



COST Action 733

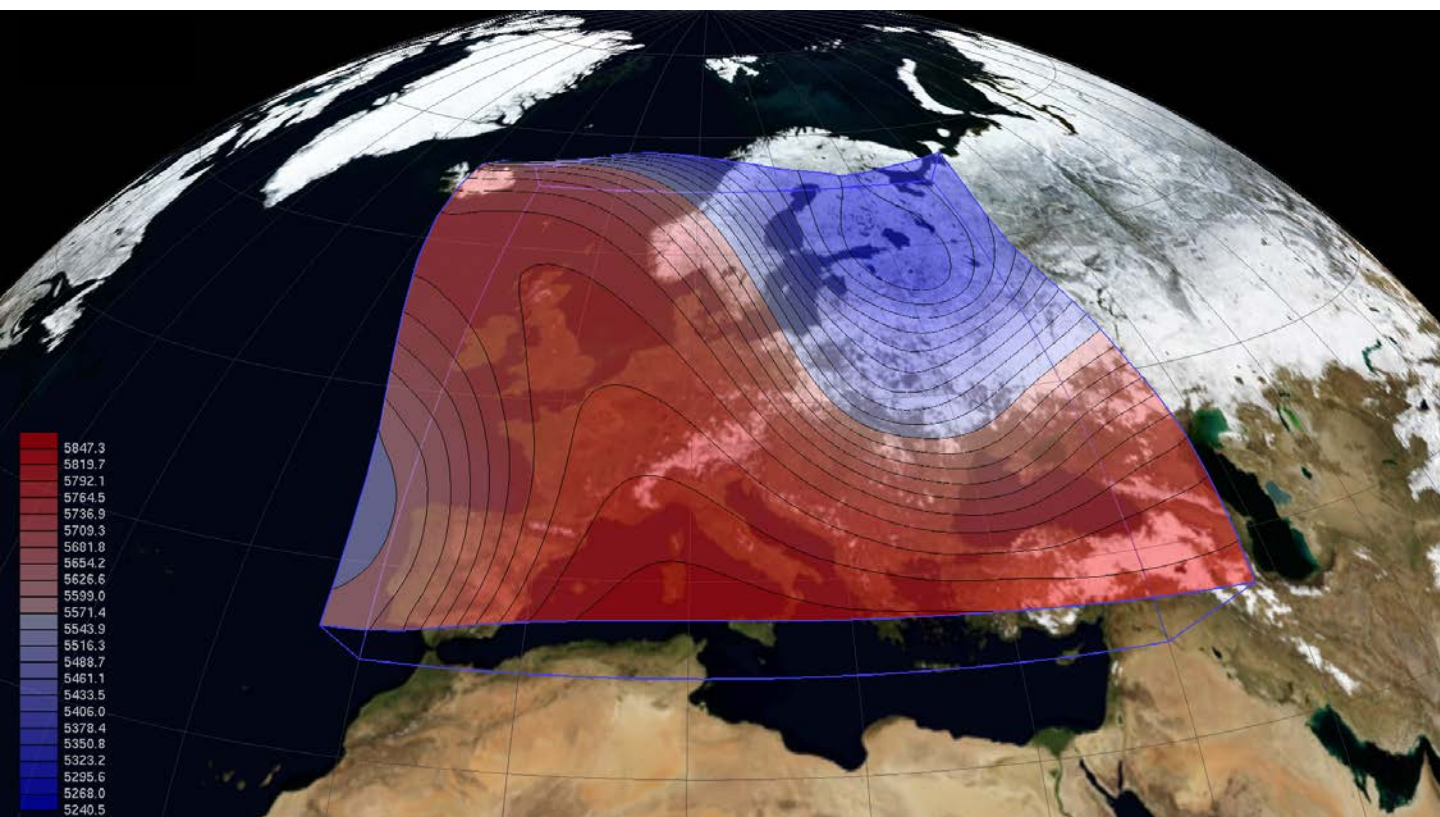
Harmonization and Application of Weather Type Classifications for European Regions

Final Scientific Report

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Title page: Image in the bottom shows the 500 hPa geopotential height level (levels between 5240 and 5847 gpm) for the 20th of April 2016, the date when the final meeting for the publication of this report took place in Vienna.

Abstract

Research on relationships between large scale atmospheric circulation and different climatic and environmental variables has multiplied, and with it the need for a simple description of atmospheric conditions. This has led to renewed interest for weather and circulation type classifications. The objective of COST Action 733 was to develop a classification technique scalable to any European region for a wide range of applications. A necessity to reach this goal was to develop a general numerical approach for assessing and comparing classifications of atmospheric circulation and typical weather situations in European regions. In addition, the action aimed to increase the knowledge of the relationships between atmospheric circulation and responding weather, climate and environmental variables.

During five years the Action succeeded to produce an extensive, consistent catalogue of atmospheric circulation type classifications (COST733CAT) based on different methodological concepts. The resulting catalogue and associated classification types are produced through an open source (GPL) software developed within the Action (COST733CLASS), allowing to generate classifications from a wide number of algorithms and parameter options. Hence it provides a freedom to generate classifications tailored to any location or potential application. Criteria and procedures to systematically evaluate circulation type classifications are defined and tested, and several of these are included in the software.

The Action has provided a unique opportunity to systematically evaluate an extensive number of classifications within a coordinated inter-disciplinary environment, and has increased the knowledge on a range of classification approaches, extremely useful for developing any new weather type classification method for European Regions.

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1

Introduction

Lead author: Ole Einar Tveito

Weather or circulation type classification has engaged meteorologists and climatologists for a long time. Classification usually means to group something that can appear as complex and chaotic into something discrete, structured and easy to understand based on characteristic features of the process to be grouped. In the atmospheric sciences classifications has a long tradition. Many environmental applications require rather simple descriptions of the present atmospheric conditions. Already since ancient times people have tried to understand the connection between weather phenomena and the resulting weather and climate where they live. This knowledge became in many cultures the knowledge became structured and more and more formalized as weather lore about seasonal tendencies and anomalies. Written sources can be found as early as in the works of the Greek philosopher Theophrastus (c.371–c.287 BC). The German *Die Bauern-Praktik* (first published in 1508) included a wide collection of medieval weather lore where included.

During the last century investigations trying to explain and understand the relations between the larger scale atmospheric behaviour and local weather and climate response, eventually leading to weather and circulation type classifications have been numerous. The first works by among others Dove, Köppen and Abercromby was relating surface winds to observed station weather. Later subjective evaluation/interpretation of synoptic maps was used to classify the atmospheric circulation (among others the well-known Hess-Brezowski Grosswetterlagen or the Lamb weather types). These early subjective classifications were used mainly for weather forecasting purposes. In the recent decades has however the application of circulation classifications widened. The advance of computers made it possible to develop and apply automated methods and classification techniques and their applications play today an important role in the field of statistical climatology. A large number of classifications have been developed using the opportunity given by computers and tools offered by statistical software. The high number of different methods applied for classification of circulation types implies open challenges to

the meteorological-climatological communities. Most circulation type classifications are:

- adapted to a specific region, and not necessarily easily transferable to another region.
- focused on a specific (environmental) problem, and the spatial and temporal scale are adapted to this purpose.

For these reasons, there are difficulties in comparing and evaluating the various weather types classifications per se as well as the applications using these classifications. There is therefore a need for a coordinated European initiative in order to produce one or a few standard methods designed to facilitate such comparisons. COST Action 733 was initiated in order to establish a unified, transferable approach to synoptic classifications. The motivations for the Action were:

- weather types classifications are still needed and used for a wide range of applications,
- it is undesirable that so many different weather types classifications are available,
- there is no common reference weather types classification for European regions,
- there is a need for developing criteria for comparing weather types classifications.

1.1 Aims and objectives

The Memorandum of Understanding for COST733 was approved at the 161st COST CSO Meeting 15–16, March 2005. The MoU states that the main objective of the COST733 Action was to achieve a general numerical method for assessing, comparing and classifying typical weather situations in European regions. The method should have the following features:

- scalable to any European (sub)region with time scales between 12 h and 3 days and spatial scales of ca. 200 to 2000 km,
- applicable for:
 - frequency analysis of extreme weather events,
 - local climate assessment (e.g. fog/snow cover/sunshine duration),
 - human biometeorology and impacts on ecosystems,
 - climate monitoring,
 - assessment of impaired air quality episodes,

- medium range weather forecast and climate characteristics of the forecast period (e.g. by mapping of climate parameters related to historic weather types and application to the forecast meteorological situations),
- verification of numerical weather forecast models (by checking the forecast weather types)

Secondary objectives was:

- to enhance our knowledge on linkages between the atmospheric circulation, weather, climate and environmental variables,
- to have an up-to-date overview of existing weather types classification methods,
- to identify suitable criteria/indicators to circulation types,
- to identify a set of useful applications of circulation types classifications,
- to analyse the strengths and weaknesses of the methods for different applications,
- to establish a (new) scientific cooperation forum in synoptic climatology in Europe,
- to provide tools for comparison and evaluation of different circulation and weather type classifications,
- to assess different methodologies for the comparison of circulation type classifications.

During the course of the Action it became early clear that the aim to establish one general classification method for all regions, scales and applications was ambiguous. The Action has therefore not been concentrating on one method, rather on a suite of methods fulfilling the specifications given in for the primary objective.

1.2 Pre-COST733 Status

Circulation type classifications for European regions began to be established more than a half century ago, e.g. by [BAUR et al. \(1944\)](#), forming the basis for the well-known ‘Grosswetterlagen’ of Hess and Brezowsky ([HESS and BREZOWSKY, 1952](#)). There are circulation type classifications which have continuously been applied for along period of time. One of the longest series is based on the H.H. Lamb’s method ([LAMB, 1972](#)), consisting of daily circulation patterns over the British Isles since 1861. Another one is the daily ‘Grosswetterlagen’ of [HESS and BREZOWSKY \(1952\)](#), reprocessed in a 5th edition by Gerstengarbe and Werner ([GERSTENGARBE and WERNER, 1999](#)), starting from 1881 until today. These classifications were set up as manual subjective classifications. Since the availability of numerical weather

analyses (as a step to numerical weather prediction), weather types classifications were based on the automatic evaluation of grid point values, e.g. by GROLL (1976) or BÉNICHOU (1985). Some of the circulation types classifications have become routine applications, e.g. the objective weather types classification of the German Meteorological Service (BISSOLLI and DITTMANN, 2001).

In the light of the debate on Climate Change and its impact on Ecosystems, classification types classifications gained interest, because a changing circulation structure could be one of the keys for understanding the changing climate. SHERIDAN (2002) wrote in his paper: *Synoptic weather-typing, or the classification of weather conditions or patterns into categories, continues to be popular, and numerous methods have been developed over the past century. The recent increased interest in the procedure is attributed to its utility in solving a wide array of applied climatological problems. Concern over the impacts of weather, especially for the purpose of understanding possible implications of climate change, has driven the search for more, and better, weather-typing schemes.*

Circulation types are indeed used to describe and understand the physical links between atmospheric circulation modes, synoptic features, and surface weather at various scales. Relationships between circulation classification schemes and surface weather variables are used for the downscaling (i.e., transfer to smaller scales) of climate model results. Appropriate circulation types classifications for downscaling have been investigated during the project ACCORD (Atmospheric Circulation Classification and Regional Downscaling JONES et al., 2000). ACCORD was followed by another EU project named STARDEX (Statistical and Regional Dynamical Downscaling of Extremes for European Regions, 2002-2005; see <http://www.cru.uea.ac.uk/projects/stardex/> for more details), which focused in particular on an intercomparison of downscaling methods describing scenarios of extreme events.

The principle of circulation type classifications are also used in statistical downscaling of GCMs (AOGCMs) where relations between large scale pattern characteristics (often pressure or geo-potential heights) of the GCMs and observations of a response variable (e.g. temperature or precipitation) are established. These relations are though not used to classify since the relations are continuous and classifications by nature a discrimination of a process.

1.3 Organisation into four working groups

1.3.1 Working Group 1: Existing methods and applications

WG1 was running during the first phase of the action focusing on the state of the art of circulation type classification methods and their applications. It was divided into 3 subgroups (A), (B) and (C):

- WG 1A: Inventory of existing weather types classifications,
- WG 1B: Identification of requirements of various applications,

..... 1.3 Organisation into four working groups

- WG 1C: Selection of classification methods and of applications to be assessed by the Action.

The activity and results of WG1 established the platform for the further activities of the Action, and are presented in detail in Chapter 2.

1.3.2 Working Group 2: Implementation and development of weather types classification methods

WG2 has been focusing on the circulation type classifications. It has prepared the circulation type catalogues (COST733CAT) of the methods selected by WG using ERA40-data as input. Further it has assessed features from the different selected methods to be combined in new common methods. WG2 has developed a number of tools for producing and assessing circulation type classification. The main result of WG2 is an open source software package for classifying atmospheric circulation COST733CLASS. Chapter 3 gives a detailed description of the results and achievements of WG2.

1.3.3 Working Group 3: Comparison of selected weather types classifications

The focus of WG3 has been evaluation and intercomparison of the circulation type classifications included in COST733CAT. The objective of the WG was to define statistical measures or tools for comparing circulation type classifications. These approaches were categorised in basic evaluation, synoptic-climatological evaluation and subjective evaluation. The findings of WG3 are presented in Chapter 4 of this report.

1.3.4 Working Group 4: Testing methods for various applications

Application of circulation type classifications in various applications has been the focus of WG4. The classifications included in the various versions of COST733CLASS has been applied and evaluated for a number of applications within:

- Climate change and variability
- Hydrology
- Air pollution
- Risk and hazards
- Forest fires
- Climatological mapping

The extensive activities of WG4 are reported in Chapter 5.

Working Group 1: Existing Methods and Applications

Lead author: Radan Huth

2.1 Introduction

The first step within the COST Action 733 “Harmonization and Applications of Weather Types Classifications for European Regions” was the completion of work in WG1 “Existing Methods and Applications”. As a major undertaking in WG1, an inventory of already existing classifications has been accomplished by submitting a questionnaire to the scientific community. The outcome of this questionnaire provides a first overview about the spatial and temporal resolution, methods, number of types, and purpose of the classifications. The questionnaire and its outputs were already described in [HUTH et al. \(2007\)](#), and major information on it was repeated in [HUTH et al. \(2008\)](#).

2.2 Questionnaire and response

Based on the agreement made at the kick-off meeting in Brussels, a questionnaire on the existing circulation/weather classifications, their applications, and comparison studies, was prepared. The questionnaire consists of 40 questions (see Tab. 2.1), concerning different aspects of the classifications (methods, datasets, spatial and temporal resolution, references, etc.), experience with the ERA-40 dataset, comparisons between different methods, and basic personal information about the respondent. The questionnaire was sent out to the members of the Management Committee, other persons who had expressed their interest to participate, and those suggested by members of the MC as potential contributors. Over 80 responses were received in the end: in many cases, these were multiple

responses from a single person or institution. This ensures a satisfactorily good coverage as to the topics and region. The countries from which a response was received are: Austria, Belgium, Croatia, Cyprus, Czech Republic, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Lithuania, the Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovenia, Spain, Sweden, Switzerland, and United Kingdom. Of the relevant large and medium-sized European countries (except for former U.S.S.R.), only Ireland, Denmark, Slovakia, and Bulgaria did not provide a response. The involvement of individual countries is quite varied, e.g. Spain and Germany are highly active in this field: see Tab. 2.2 for numbers of classifications reported in individual countries.

Table 2.1: Questions posed in the questionnaire.

<i>Nr. Question</i>	
1	Main name of the WTC
2	Other official or nonofficial names used
3	Region of the initial (original) application
4	Horizontal scale (micro, meso, macro, local)
5	Horizontal range (in km)
6	Geographical coordinates (<i>e.g. 50–55° N, 10–20° E</i>)
7	Geographical region, country (<i>e.g. Eastern Alps, Austria</i>)
8	Author, authors, team
9	Year of the first official entrance (<i>e.g. documented official use or publication</i>)
10	Details of the first documentation or publication (<i>name, date, place</i>)
11	Eventual further developments, amendments, publications
12	Type of classification (<i>e.g. manual, automatic, subjective, objective or other</i>)
13	Time scale (resolution) (<i>e.g. daily, decadal</i>)
14	Classification purpose (<i>e.g. weather forecast and prediction, applied synoptic climatology</i>)
15	The number of classified types/units
16	Main elements describing WTC (<i>e.g. air advection, baric field, weather elements</i>)
17	Source data/data base used for types selection (distinguishing) (<i>e.g. slp data, 700 hPa height</i>)
18	Methods used for types selection (distinguishing) (<i>e.g. manual map analyzing, cluster analysis</i>), Please shortly describe
19	Criteria used for types selection; are they based mainly on physics/meteorology or statistics
20	Does WTC run operationally?, if yes where?
21	Other regions where the specified above classification was applied or adopted
22	If yes, please specify and briefly describe
23	If yes, please give documentation/publication (<i>see point 10</i>)

continued on next page

<i>Continuation</i>	
<i>Nr. Question</i>	
24	The main limitations of the WTC
25	Any other remarks
26	Your personal experience with the respective WTC or other (eventual projects, publications)
27	Did you work with gridded data sets, if yes please specify?
28	Have you ever worked with ERA40?
29	Did you apply ERA40 data for WTCs?
30	What is your experience?
31	Is it possible to apply the WTC you use to ERA40 data?
32	Have you ever compared different WTCs?
33	Which methods did you use for comparison?
34	Do you prefer a certain WTC, if yes, why?
35	Do you know any references for comparison studies (publications, web addresses, etc)?
36	Remarks
37	First and last name
38	Institution
39	E-mail
40	Date

Table 2.2: Numbers of classifications in individual European countries reported in the questionnaire.

<i>Country</i>	<i>Number of classifications</i>
Austria (AT)	3
Belgium (BE)	1
Croatia (HR)	1
Cyprus (CY)	1
Czech Republic (CZ)	3
Estonia (EE)	2
France (FR)	4
Germany (DE)	9
Greece (GR)	3
Hungary (HU)	4
Lithuania (LT)	1
The Netherlands (NL)	1
Norway (NO)	2
Poland (PL)	5

continued on next page

<i>Continuation</i>	
<i>Country</i>	<i>Number of classifications</i>
Portugal (PO)	1
Romania (RO)	4
Russia (RU)	3
Serbia (SB)	1
Slovenia (SI)	3
Spain (ES)	12
Sweden (SE)	2
Switzerland (SW)	2
United Kingdom (UK)	4

2.3 Analysis of the response

2.3.1 General remarks

A trivial and expected observation is that the classifications are varied in all of their aspects. A few procedures were reported, which in fact are not classifications; the possible implication is that the terms ‘classification’ and ‘weather/circulation types’ are not perceived by all meteorologists and climatologists in the same way. Such procedures are excluded from further analysis. The inventory reflects three different activities relevant for the COST Action, i.e., the development of own classifications, the application of already existing classifications to new regions/datasets, and comparison studies of several classifications. The most frequently used classifications are the Lamb and Hess-Brezowsky catalogues, including their various modifications and objectivized versions; among the objective methods, the k-means method of cluster analysis prevails.

2.3.2 Temporal resolution

The large majority (84% of reported classifications, see Fig. 2.1) operate on a daily basis. Altogether 9% of classifications operate on a shorter time scale, viz.,

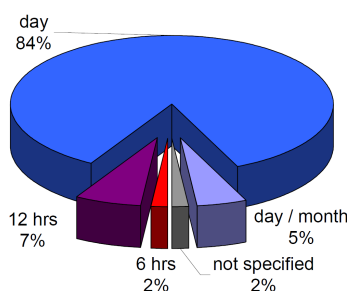


Figure 2.1: Percentage of reported classification methods as for their temporal resolution.

12 and 6 hours. However, the difference is not due to a specific methodology, but results mainly from data availability. Only 5% of classifications were operated on a monthly basis, but all with a remark that a daily timestep is also possible or has already been applied.

2.3.3 Spatial scales

As Fig. 2.2 displays, the information about the horizontal scale, resolution, and geographical coordinates of the database was somewhat subjectively transformed into general qualitative information on the spatial scale in five different classes: (i) continental (involving whole Europe with adjacent parts of the Atlantic Ocean, or at least a major part of Europe—typically more than 30° of latitude by 40° of longitude), (ii) sub-continental (involving large parts of Europe – typically of about 20° by 20°), (iii) country (involving a single country or a group of small countries, possibly including its/their close neighbourhood), (iv) regional (only a part of a single country), and (v) local (single station). Larger-scale classifications prevail: The half of all classifications are of a continental scale, about 20% of them are of sub-continental and of country scale. The rest (8%) includes regional and local scales. All the local-scale classifications are based on weather, not circulation variables (see below).

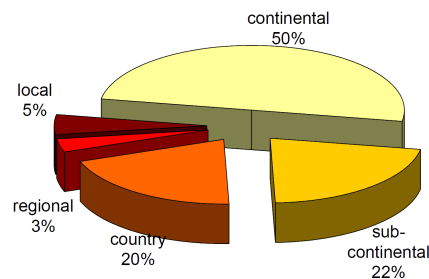


Figure 2.2: Percentage of reported classification methods as for their spatial scale.

2.3.4 What is classified?

The largest number of classifications (84%, cf. Fig. 2.3) is based on variables describing baric fields (SLP, geopotential heights), usually gridded or in a map form, in some cases together with other variables (typically thickness, temperature, humidity). These are referred to as ‘circulation classifications’ and are principally what the COST733 Action is supposed to concentrate on. One classification is based on cyclone trajectories. The ‘weather classifications’ (8%) are based on surface weather variables at a single station or a group of close stations, and frequently employ the diurnal cycle of the variables. One classification can be referred to as ‘airmass’ since it utilizes variables suitable for characterizing airmasses, viz., temperature and humidity, over a small area. One classification combines ‘circulation’ and ‘weather’. Another classification is based on regional precipitation patterns.

It is important to note that the share of classifications other than the circulation-based ones is likely to be underestimated because the respondents were requested to concentrate on circulation. As a result, the airmass- and weather-based classifications were to some extent overlooked.

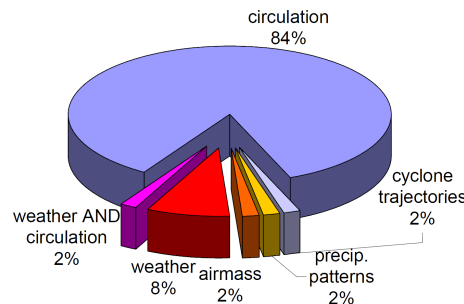


Figure 2.3: Percentage of reported classification methods as for the data on which classification is performed.

2.3.5 Approach

Three basic approaches to classification may be distinguished according to whether the definition of types and the attribution to them is done in a subjective or objective manner (e.g., [HUTH et al., 2008](#)): (i) subjective – the types are defined and patterns are classified subjectively; (ii) objective – the types are defined and patterns are classified objectively; (iii) mixed – the types are defined subjectively but the classification procedure is objective. The mixed approach is typically used in the objectivized subjective catalogues. Of the classifications reported, 30% are subjective, 25% are mixed, and 45% are objective, see Fig. 2.4 (a).

Several objective methods are used in classification studies [see Fig. 2.4 (b)]: cluster analysis (most frequently k-means method is used, but also hierarchical methods of average linkage are reported) has the largest share (30% of the total). Other methods are represented by PCA (2 responses), correlation (Lund) method (one response), and classifications based on physical criteria, which have not been clearly described (one response). In 8% of cases, the objective method is not specified or its description is more or less misleading. The mixed methods [Fig. 2.4 (c)] include 7 cases of the objectivized Lamb catalogue (Jenkinson-Collison method and its derivatives), 2 are objective versions of the Hess-Brezowsky catalogue, and 6 others are based on authors' own subjective classifications.

2.3.6 Number of types

The number of resulting types varies widely from 4 to 40. Some of the methods allow also sub-types to be determined, of which the largest number is 209. Several objective methods produce variable numbers of clusters, depending on the dataset subject to classification; their respondents either do not specify possible numbers of classes or indicate their usual range. The numbers of types are distributed fairly

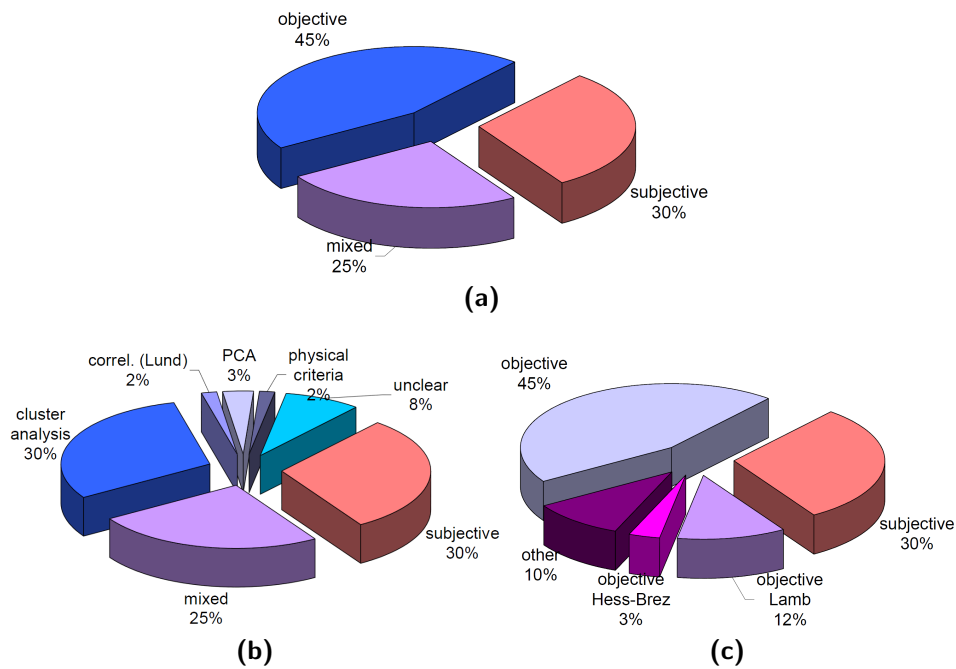


Figure 2.4: (a) Percentage of reported classification methods as for the approach; (b) as in (a) with a subdivision of objective methods; (c) as in (a) with a subdivision of mixed methods.

evenly in the groups of classifications with 4 to 8, 9 to 14, 15 to 20, 21 to 29, and over 30 classes (see Fig. 2.5).

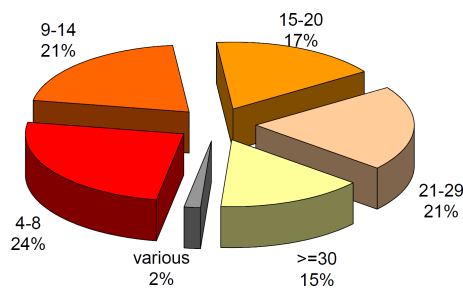


Figure 2.5: Percentage of reported classification methods as for the number of types.

2.3.7 Purpose

Many different purposes of classifications have been reported. Many respondents used the wording suggested as an example, which is rather general (e.g., applied synoptic climatology, weather prediction), others were fairly specific. Anyway, two broad, partially overlapping families of purposes can be identified: meteorological and climatological. Among the meteorological purposes, weather prediction includes specific answers such as verification, forecast adjustments, seasonal forecasting, and avalanche forecasting. Other meteorological purposes include air pollution/quality, objective analysis of precipitation, and medicine meteorology.

Climatological purposes include applied synoptic climatology, which is very general; its several specifications include precipitation, forest fires, and human health. Other general responses are dynamical climatology and climatology/climate analysis. More specific climatological purposes include long-term climate and circulation changes, climate model validation, analysis of relationships between circulation and surface weather/climate, statistical downscaling, conditional weather generator, wind atlas, and (one may wonder if it can really be included among climatological purposes) fish capture. A few other general purposes were reported: research, documentation, and teaching.

2.3.8 Comparisons

Slightly more than a half of the responses claim that the respondent has an experience with comparisons among different classifications. However, it is frequently unclear whether the comparison relates to the classification method reported or to respondent's general knowledge. Many responses omit stating any more details and results of the comparison, e.g., which methods were compared, which method to prefer, etc. The comparison studies are difficult to count since in multiple responses from a single respondent, the same information on the comparison regardless of the method reported is typically given. Useful for further work in the COST733 Action are a couple of references to intercomparison studies the respondents are aware of.

2.4 Pre-selection of classification methods

The classification methods reported in the questionnaire responses were surveyed, resulting in a total of 65 methods. Of them, an optimal set of methods was selected, which would be studied and elaborated in more detail in the subsequent WGs. There were almost 70 methods reported in the questionnaire returns. An initial analysis was undertaken to remove those methods which were clearly not appropriate for use in COST733. These included methods which were too local in scale or based on local correlations with highly specific quantities, thus being unable to define synoptic-scale types. Other methods were rejected by having too few types (therefore having too little informational value) or being based only on mid-tropospheric variables (therefore yielding types with too little surface structure), or having too many types and sub-types (therefore having too little focus and relevance). Where several WTCs were based on essentially the same generic method (e.g. Jenkinson-Collison), only a single, representative method was retained. Several WTC authors were also contacted in cases where availability or detail was unclear in order to clarify whether their methods should be included or not. In particular, a number of promising methods could not be used because no digital catalogue could be provided. The list of 25 methods selected for further elaboration is provided in Tab. 2.3. The list of methods not selected for further work is shown in Tab. 2.4 together with reasons why they had been rejected.

Table 2.3: List of methods selected for further elaboration.

<i>Country of respondent</i>	<i>Author</i>	<i>Abbreviation</i>	<i>Method</i>
AT	ZAMG staff	ZAMG	subjective
AT	Lauscher, modified by Hader and Rudel	Lauscher	subjective
BE	Epicum, Bodeux and others	–	cluster analysis
CH	Schüepp et al.	AWS Schüepp	subjective
CH	Perret	Perret	subjective
CY	Michaelides	–	artificial neural networks
CZ	Huth	–	PCA in a T-mode
DE	Dittmann et al.	OWTC, WLK, OWLK	physical criteria: cyclonicity, humidity, air advection direction
DE	Beck, Jacobeit	–	geometrical prototypes
DE	Philipp, Della-Marta Jacobeit, Wanner, Fereday	SANDRA	cluster analysis (non-hierarchical by simulated annealing)
DE	Enke, Spekat	–	screening discriminant analysis
EE	Post, Tuulik and Truija	–	PCA
ES	Petisco	–	cluster analysis
ES	Esteban, Martin-Vide, Mases	–	PCA + cluster analysis (k-means)
ES	Rasilla	–	discriminant analysis
GR	Maheras	–	subjective
HU	Hess, Brezowsky	GWL, GWT	subjective
HU	Peczely	Peczely	subjective
LT	Misiuniene, Bartkeviciene	–	subjective
NL	Kruizinga	P27	EOF
NO	Lund	Lund	correlation
SI	Cadez	–	subjective
UK	James	objective Grosswetterlagen	pattern correlation with GWL-Composites
UK	James	2nd generation Lamb Weather Types	Generic LWT method (cyclonicity, flow direction)
SB	Todorovic	–	subjective

Table 2.4: List of methods removed from further elaboration. A reason for rejection is also given.
*) Methods differ in the variables used and purpose.

<i>Country of respondent</i>	<i>Author</i>	<i>Method</i>	<i>Reason for rejection</i>
AT	Seibert, Frank, Formeyer	cluster analysis	selection too specific, too few types
CZ	Huth et al.	PCA and cluster an. (avg.linkage)	rejected on advice from Huth
CZ	Brádka	adaptation of Hess-Brezowsky to Czechoslovakia	too similar to Hess and Brezowsky—removed upon advice from Huth
DE	Kreienkamp, Enke	screening discr. analysis*)	selection too specific, too few types
DE	Kreienkamp, Enke	screening discr. analysis*)	redundant
DE	Enke, Kreienkamp	screening discr. analysis*)	selection too specific
DE	Enke, Kreienkamp	screening discr. analysis*)	selection too specific, too few types
EE	Post, Tuulik, Truija	Lamb’s automated classification	redundant
ES	Rasilla	PCA and cluster an. (avg.linkage and k-means)	too few types
ES	Petisco, Herreros	cluster an. with iter. of centroids	redundant (Petisco better)
ES	Tulot	subjective	not available digitally
ES	Martin-Vide	subjective	not available digitally
ES	Fernandez	cluster analysis (iter. process using Miller’s discriminant)	author has sadly died, no-one else has sufficient knowledge of the method
ES	Lines	subjective	needs lower troposphere
ES	Rasilla	Lamb	redundant
ES	Ribalaygua, Boren	cluster analysis	selection too specific
ES	Esteban, Jones, Martin-Vide, Mases	PCA and cluster an. (k-means)	selection too specific, too few types
FI		several responses; none is real classific.	these are not WTCs
FR	Sanchez-Gomez et al.	PCA and cluster an. (k-means)	needs lower troposphere, too few types
FR	Benichou	cluster analysis	not a real WTC (10 types per parameter)

continued on next page

..... 2.4 Pre-selection of classification methods

<i>Continuation</i>			
<i>Country of respondent</i>	<i>Author</i>	<i>Abbreviation</i>	<i>Method</i>
FR	Meteo-France	cluster analysis	rejected on advice from Jourdain–non-operat. and k-means clustering already avail. from ES-Esteban
FR	Meteo France	weighted distance (?)	selection too specific, too few types, need lower troposphere
GR	Maheras et al.	not clearly specified (spatial methods of topology and geometry)	too unclear, for a local classification the subj. method of Maheras is more useful
GR	Maheras et al.	?–spatial methods of topology and geometry	ditto
HU	Ambrozy, Bartholy, Gulyas	cluster analysis (k-means)	needs lower troposphere
HU	Bartholy, Barnston, Livezey	PCA and cluster an. (k-means)	needs lower troposphere
IT		two answers; none is a real classification	not a real WTC
NO	Lamb, Jenkinson, Collison	Jenkinson and Collison	redundant
NO	Hanssen-Bauer et al.	not a classification	not a real WTC
PT	Trigo, da Camara	similar to Jenkinson and Collison	too general (not really synoptic types)
RO	Plaut	cluster analysis	too few types
RO	Hess, Brezowsky	Hess, Brezowsky	redundant
RO	Topor, Stoica	subjective	too few types
RO	Ion-Bordei, Stefan et al.	cyclone trajectories – subjective	too few types
SE	Lamb, Jenkinson, Collison	Jenkinson-Collison	redundant
SE	Linderson	Jenkinson-Collison	redundant
continued on next page			

<i>Continuation</i>			
<i>Country of respondent</i>	<i>Author</i>	<i>Abbreviation</i>	<i>Method</i>
SI	Gabersek	?	too few types, for a local classification the subj. method (Cadez) is more useful
SI	Rakovec, Vrtacnik	maximum explained variance	too few types, selection too specific
UK	Jenkinson, Collison, Jones	Jenkinson-Collison	redundant (will use one generic objective Lamb method and apply to different regions)
UK	McGregor	PCA and cluster an.	selection too specific, too few types

2.5 Recommendations to other WGs

The classifications reported are so varied that the exercise of mutually comparing them on a unified dataset seems to be very useful and of great importance for a broad meteorological and climatological community.

It is important to distinguish between circulation, weather, and airmass types (classifications) because these terms are not interchangeable and each is supposed to refer to a different database on which the classification is developed. Indeed, an overlap between the three groups is possible.

The work of COST733 should concentrate on truly circulation classifications. The weather and airmass classifications, although they are certainly important and also deserve a detailed examination, will not be considered further in COST733.

Any selected weather type/circulation classification has to be “automated”, that means objective, consistent and it should be implemented on a computer basis.

Any type, identified in the classification, should have a clear physical meaning even when a statistical approach has been used to defined it in order to avoid as much as possible any statistical artifacts.

The classifications, should be run on a unified reference gridded dataset, e.g. ERA40 (in order to cover longer periods).

Based on the applications reported in the questionnaire responses, the most useful time scale for the classifications is the daily scale. A higher time resolution does not seem necessary, at least at this stage.

All codes belonging to the selected methods should be distributed as freeware code at least among all the COST733 participants.

Working Group 2: Implementation and development of weather types classification methods

Lead Author: Andreas Philipp

The task of Working Group 2 was to establish a database of circulation type classifications using the methods selected by working group 1. This database is the basis for working groups 3 and 4 which should evaluate and apply the classifications in order to find preferable methods and suitable configuration aspects for classification. Recommendations from these working groups in turn should be implemented by working group 2 for further developments of classification methods and their configuration.

In the course of the COST action a distinction has been established between the classification method itself (the algorithm) and the configuration of these methods and the input data. Quickly it turned out that configuration parameters like the number of types or the decision which meteorological parameter is used is very important for the outcome. However, most of these configuration parameters can be applied to many different classification methods/algorithms. In order to achieve statements about the performance of certain classification *methods* the configuration should be held constant for all methods. In the following the standardization of the configuration will be described in Section 3.1 while the algorithms are explained in Section 3.2. Subsection 3.3.1 provides detailed information about the different versions of the classification datasets while Section 3.4 introduces the software package COST733CLASS which was developed and used to calculate the classification catalogs and is available for developments beyond the COST Action 733.

3.1 Definition of standardized classification configurations

One of the first tasks for Working Group 2 (WG 2) and the whole action was the agreement on a distinct input data set to which the methods should be applied. Another early decision was the definition of spatial standard domains and their spatial resolution and the temporal resolution of the classification procedure. A first feedback from WG 3 however made clear that also the number of types needs to be addressed as an important configuration parameter. Further considerations then addressed the meteorological input parameters, seasonally separated calculations and the use of sequences of days instead of single day calculations.

3.1.1 Input data set

In order to avoid discrepancies due to different data sources a common dataset has been selected. The use of reanalysis data was preferred in order to avoid missing values or inhomogeneities. The NCEP/NCAR reanalysis ([KALNAY et al., 1996](#)) has been discussed as a candidate, however due to the availability of higher spatial resolutions (up to $1^\circ \times 1^\circ$ instead of $2.5^\circ \times 2.5^\circ$) the decision was made for the ERA40 dataset provided by the European Centre for Medium-Range Weather Forecasts ([UPPALA et al., 2005](#)), which is available for the period 09/1957–08/2002 and in 6-h time steps.

The ERA40 input data have been converted from GRIB format to ASCII and NETCDF to make calculations easier for the contributors of catalogues. Within the ASCII files, which are still available for reproduction of the catalogs, the first column represents the grid point at the south-western edge of the domain; the second column represents the grid point at the southern boundary latitude and second longitude from the west. The last column represents the grid point at the north-eastern edge.

3.1.2 Definition of spatial domains

Spatial standard domains should cover different aspects for application of classification methods. One important aspect is the location of the domain, i.e. which climatic region is addressed, another is the size of the domain which decides on the number of synoptic circulation phenomena which are covered.

In order to be able to evaluate the effect of spatial differences one large pan-European domain has been defined beside 11 smaller domains located in different regions of Europe but, sometimes overlapping, covering nearly the whole landmass of Europe. Tab. 3.1 provides the coordinates and grid point information of these domains. The largest is covering the entire Europe domain (domain 0) using 32×24 grid points at a reduced resolution of 3° longitude by 2° latitude, while the smallest is confined to the greater Alpine area (domain 06) comprising 12×18 grid points at 1° resolution. All methods were applied to all 12 domains.

..... 3.1 Definition of standardized classification configurations

Table 3.1: Spatial domains: identification numbers, names and coordinates of spatial domains defined for the classification input data, from PHILIPP et al. (2010). *DD*: Domain Number; *# GP*: Number of grid points.

<i>DD</i>	<i>Region</i>	<i>Longitudes</i>	<i>Latitudes</i>	<i># GP</i>
00	Europe	37°W to 56°E by 3°	30°N to 76°N by 2°	32×24
01	Iceland	34°W to 3°W by 1°	57°N to 72°N by 1°	32×16
02	West Scandinavia	06°W to 25°E by 1°	57°N to 72°N by 1°	32×16
03	Northeastern Eur.	24°E to 55°E by 1°	55°N to 70°N by 1°	32×16
04	British Isles	18°W to 08°E by 1°	47°N to 62°N by 1°	27×16
05	Baltic Sea	08°E to 34°E by 1°	53°N to 68°N by 1°	27×16
06	Alps	03°E to 20°E by 1°	41°N to 52°N by 1°	18×12
07	Central Europe	03°E to 26°E by 1°	43°N to 58°N by 1°	24×16
08	Eastern Europe	22°E to 45°E by 1°	41°N to 56°N by 1°	24×16
09	Western Mediter.	17°W to 09°E by 1°	31°N to 48°N by 1°	27×18
10	Central Mediter.	07°E to 30°E by 1°	34°N to 49°N by 1°	24×16
11	Eastern Mediter.	20°E to 43°E by 1°	27°N to 42°N by 1°	24×16

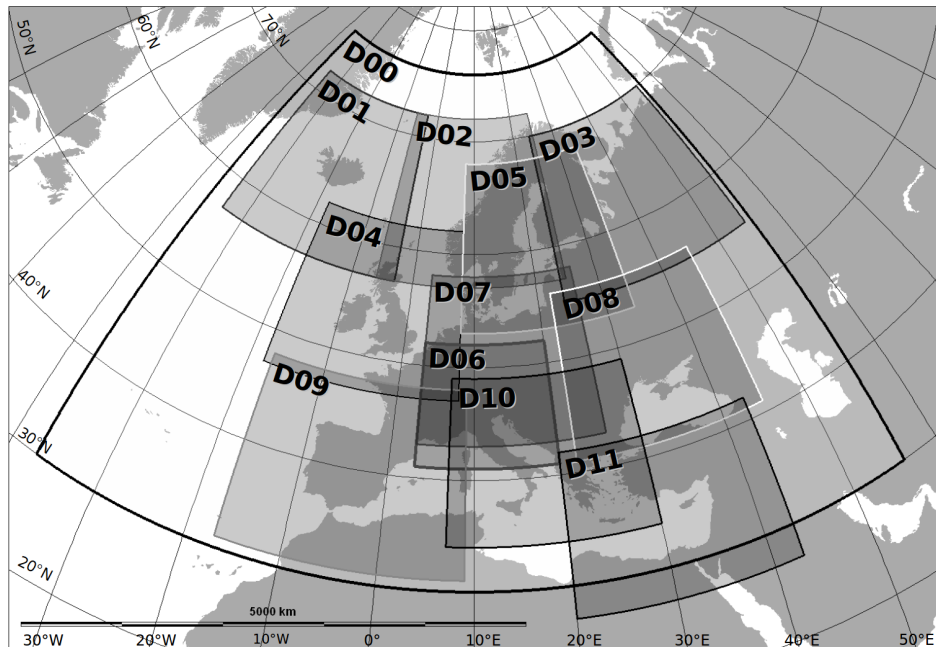


Figure 3.1: Spatial domains: identification numbers, names and coordinates of spatial domains defined for the classification input data (from PHILIPP et al., 2010).

3.1.3 Meteorological parameters

Initially the parameters shown in Tab. 3.2 were available for the analysis.

Table 3.2: ERA40 input parameters and their respective units.

<i>ERA40</i>	<i>Name</i>	<i>Units</i>	<i>Abbreviation</i>	<i>Levels [hPa]</i>
129	Geopotential	$\text{m}^2 \text{s}^{-2}$	Z	300/500/700/850/925
130	Temperature	K	T	300/500/700/850/925
131	U Velocity	m s^{-1}	U700	700
132	V Velocity	m s^{-1}	V700	700
136	Total Column Water	kg m^{-2}	TWC	—
142	Large Scale Precip.	mm	LSP	—
143	Convective Precip.	mm	CP	—
151	Mean Sea Level Press.	Pa	MSLP	—
157	Relative Humidity	%	R	300/500/700/850/925
165	U Wind/10 Metre	m s^{-1}	10mU	—
166	V Wind/10 Metre	m s^{-1}	10mV	—
167	Temperature/2 Metre	K	2mT	—

Because of the decision to concentrate on pure circulation type classification methods, for the first version of the classification catalog dataset only mean sea level pressure (MSLP) was used to calculate the catalogs. The reason for the decision on MSLP was the fact that the majority of the existing catalogs was based already on MSLP and, for comparison, all methods should be applied to the same parameter in order to exclude differences caused by the parameter used. The only exception was the method WLK which per definition needs wind components at the 700 hPa level, geopotential height on the 950 and the 500 hPa level and the total column water.

Precipitation (PRC) as a sum of large scale (LSP) and convective precipitation (CP) as well as air temperature at 2m above ground level have been used for evaluation.

These decisions about meteorological parameters have been made although it is known that there might be better suited variables depending on the purpose the classification is used for. However the focus in these analysis is clearly on comparability and consistency for comparison reasons. The aim at the first stage was not to find the very optimal configuration for a certain application. Thus MSLP might have been replaced by higher level pressure fields or other parameters.

For version 2 of the classification dataset the number of meteorological circulation parameters has been extended by thickness between 500 hPa and 850 hPa geopotential height and vorticity of the MSLP field, the 925 and the 500 hPa GPH level.

3.1.4 Temporal configuration

Albeit the ERA40 data are available in 6-hourly time steps, only the 12 GMT noon data have been used as classification input data. This corresponds to a daily resolution while avoiding the use of daily mean values which can cover certain synoptic circulation features. The time period is preset by the ERA40 dataset which covers the period 09/1957 to 08/2002.

While the first version of the catalog was based on the above-mentioned single day classification, except for one method (SANDRAS, [PHILIPP, 2007](#)), the systematic use of 4-day sequences was tested as a variant of some methods in version 2 of the catalog data set. This should allow for an assessment of effects if not only the day in question is classified but also its evolution.

3.1.5 Number of classes

All classification methods under investigation allow to use more than one fixed number of types for classification. For some methods the number of types can be chosen arbitrarily, like cluster analysis, for some others there is at least some flexibility, e.g. by defining another number of wind sectors. Originally the classifications selected by working group 1 includes numbers of types between 4 and 43. One of the first results of working group 3 however showed that an assessment of classification algorithms is blurred if different numbers of types are used.

Thus it has been decided by working group 2 to define three standard numbers of types: A small one with 9, an intermediate one with 18 and a large number of 27. Even though these numbers might appear arbitrary, they represent the majority of the original classifications and all classifications can be calculated with these numbers by a deviation not more than two types.

3.2 Description of classification methods

3.2.1 Introduction

There are different methods approaching a classification of circulation patterns, as was shown by [YARNAL \(1993\)](#), [YARNAL et al. \(2001\)](#) and [HUTH \(2010\)](#).

In order to systematize them, two criteria can be used: how the different types are determined, and how individual cases are assigned to the types. Regarding the first criteria, we can distinguish between the approaches where the types are defined prior to the assignment stage and where the types are derived and evolve during the process of classification itself. Preconceived types are established in base of the expert knowledge of the researcher, or the application of some physical or geometrical properties of the atmosphere, such as a direction of airflow, its strength, and degree of cyclonicity. In both cases a high degree of arbitrary (subjective) decisions are assumed, thus it is reasonable to refer to them as subjective.

The definition of the types during the classification process criteria is supposedly guided by objective criteria, using a measure of (dis)similarity (e.g. maxi-

mization/minimization of within-/between type similarity in cluster analysis) and variance maximization (e.g. in a PCA-based classification); besides, they are consistent and reproducible. However, in many respects they also can be considered under some degree of subjectivity, since several subjective decisions enter in the classification process, e.g., the choice of the (dis)similarity measure or the number of classes.

Concerning to the second criteria, subjective methodologies rely on the visual attribution of individual patterns by a trained expert, while numerical methodologies are based on either the minimizing distance from the a priori-defined types or a more or less iterative process within the numerical algorithm.

Combining both criteria, three major groups of classifications come out:

1. The group of subjective or manual classifications.
2. The hybrid or mixed classifications, being the types defined subjectively a priori, while the cases are assigned by objective criteria.
3. The classifications where both the types are defined and cases assigned by a numerical procedure are usually referred to as objective or automated classifications.

One of the initial tasks of COST733 action (WG1) was to identify and systematize as much as possible different classification methods in Europe. From that activity an inventory of many different methodologies has come out. It provides a good overview and may be considered a reasonable representation of the existing classification activities (Tab. 3.3). All of them appear in the COST733 catalogue data set called COST733CAT, but not all are reproducible by the COST733CLASS software. In the forthcoming pages a short description of the method is provided, along with some improvements implemented in the software.

3.2.2 Methods using predefined types

Two different approaches can be included within this family. Some of them try to reproduce circulation patterns which have been previously defined subjectively, other are based on quantitative thresholds or rules to determine the allocation of each day to one class. Most of those methods are based on very simple atmospheric properties, such as the zonality or meridionality of the large scale wind flow, or the cyclonic or anticyclonic character determined by the vorticity.

Table 3.3: Circulation patterns catalogues available in the COST733 data set.

Type: Predefined	
Subtype: Subjective (manual)	
HBGW	
PECZELY	
PERRET	
ZAMG	
Subtype: Mixed (hybrid): threshold based	
GWT-prototype	
LWT2	
LIT	
WLK	
SCHÜEPP	
Type: Methods producing derived types	
Subtype: PCA based methods	
TPCA	T-mode PCA
P-27	Kruizinga
PCAXTR	Principal component analysis extreme scores.
Subtype: Leader algorithms	
LUND	Classical leader algorithm
KH	Kirchhofer types
ERPICUM	Erpicum and Fettweis
Subtype: Classifications based on optimization algorithms	
KMN	Conventional k-means with random seeds
CKMEANS	k-means by dissimilar seeds
DKM	dkmeans
KMD	k-medoids – partitioning around medoids
PCAXTRKMN	k-means using PCA derived seeds
PCACA	k-means by seeds from hierarchical cluster analysis of principal components
PETISCO	Leader algorithm with optimized key patterns
SANDRA	Simulated annealing and diversified randomization clustering
SANDRAS	sequential SANDRA
SAT	Time-constrained SANDRA
Subtype: Others	
NNW	Neural network self-organizing feature maps

3.2.2.1 Subjective (manual) classifications

In this type of classifications synoptic classes are subjectively defined a priori, and the assignment of individual cases to the types is also subjective. They are based on the expert knowledge of the researcher, which establishes the criteria to define the types and identifies the most representative or characteristic circulation patterns to explain the atmospheric conditions over a place. Subjective classifications suffer from several inconveniences, because personal interpretation biases the results. For example, they suffer from inhomogeneities due to the own subjective character of the classification method (CAHYNOVÁ and HUTH, 2009); besides most of them have only regional relevance because of the difficulties to transfer them to other regions. The addition of the effects of circulation on associated surface climate variables, such as temperature or precipitation, in order to improve the reliability of the classifications increases the spread of possibilities for different situations which results in a high number of types (29 for Hess-Brezowsky, 43 for the ZAMG-classification), that makes the results difficult to handle. For that reason, the purpose to include some of them in the classification dataset is to allow comparisons with the automated or so called “objective” classifications.

The COST733 catalog includes one of the most widely known examples of a subjective catalog, the Hess-Brezowsky, which has some national derivatives, besides three other regional examples, such as the Peczely classification focusing on the Carpathian basin, Perret’s and ZAMG’s classifications focusing on the alpine region.

HBGW (HBGWL/HBGWT)

One of the most famous synoptic catalogs is the European Grosswetterlagen, initially developed by BAUR (1948) and revised and further extended by HESS and BREZOWSKY (1952) and more recently by GERSTENGARBE and WERNER (1999). It is focused on central Europe, and relies heavily on the movement of the air masses through the flow direction, recognizing three basic types (zonal, mixed and meridional) which are further split into 10 Grosswettertypen (HBGWT) and on the last hierarchical level into 29 Grosswetterlagen (HBGWL) and one undefined or transitional type.

An objectivized version of this catalogue, called OGWL (objective Grosswetterlagen) was designed by JAMES (2007) using only sea level pressure (MSLP) and geopotential height at 500 hPa (Z500) composites of the 29 original types and subsequently assigning the daily circulation patterns to them (Fig. 3.2). This was done for winter and summer separately and by applying temporal filters in order to achieve a minimum persistence of 3 days. In the COST733CAT dataset an additional unfiltered version based solely on MSLP is also included.

PECZELY’s catalogue

This catalogue was devised by G. Péczely (PÉCZELY, 1957), a Hungarian climatologist and professor of the Szeged University, Hungary (1924–1984); lately,

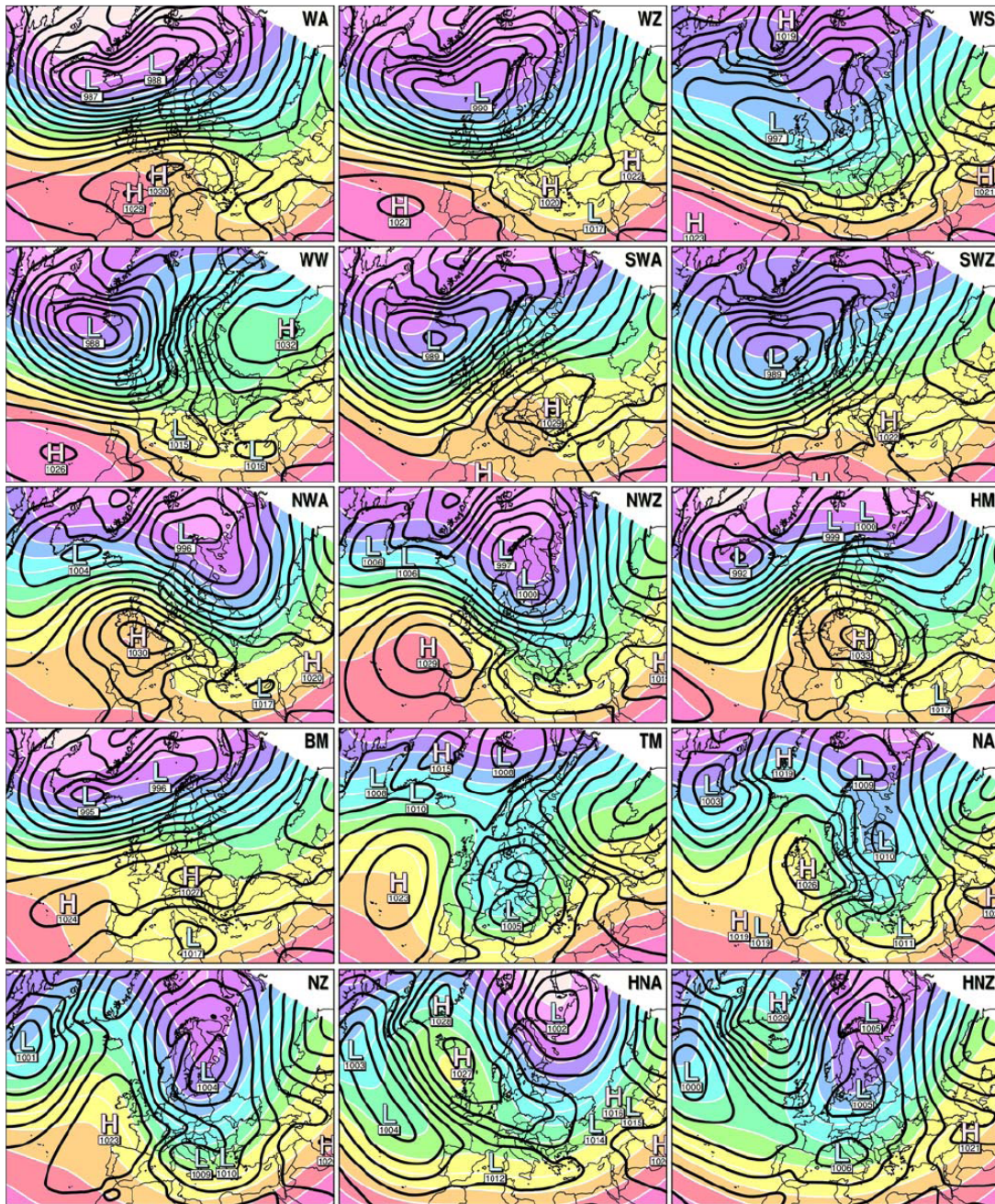


Figure 3.2: An example of the objectivized HBGW, (from [JAMES, 2007](#)).

C. Károssy has updated the classification till present ([KÁROSSY, 1994, 1997](#)). This subjective classification is based on the geographical location of cyclones and anticyclones over the Carpathian basin, however the positions of cold and warm fronts were also considered; for that reason, it is not reproducible by the COST733CLASS software. The whole catalogue comprises only 13 types, combining meridional-northern, meridional-southern, zonal-western, zonal-eastern and central types (Fig. 3.3).

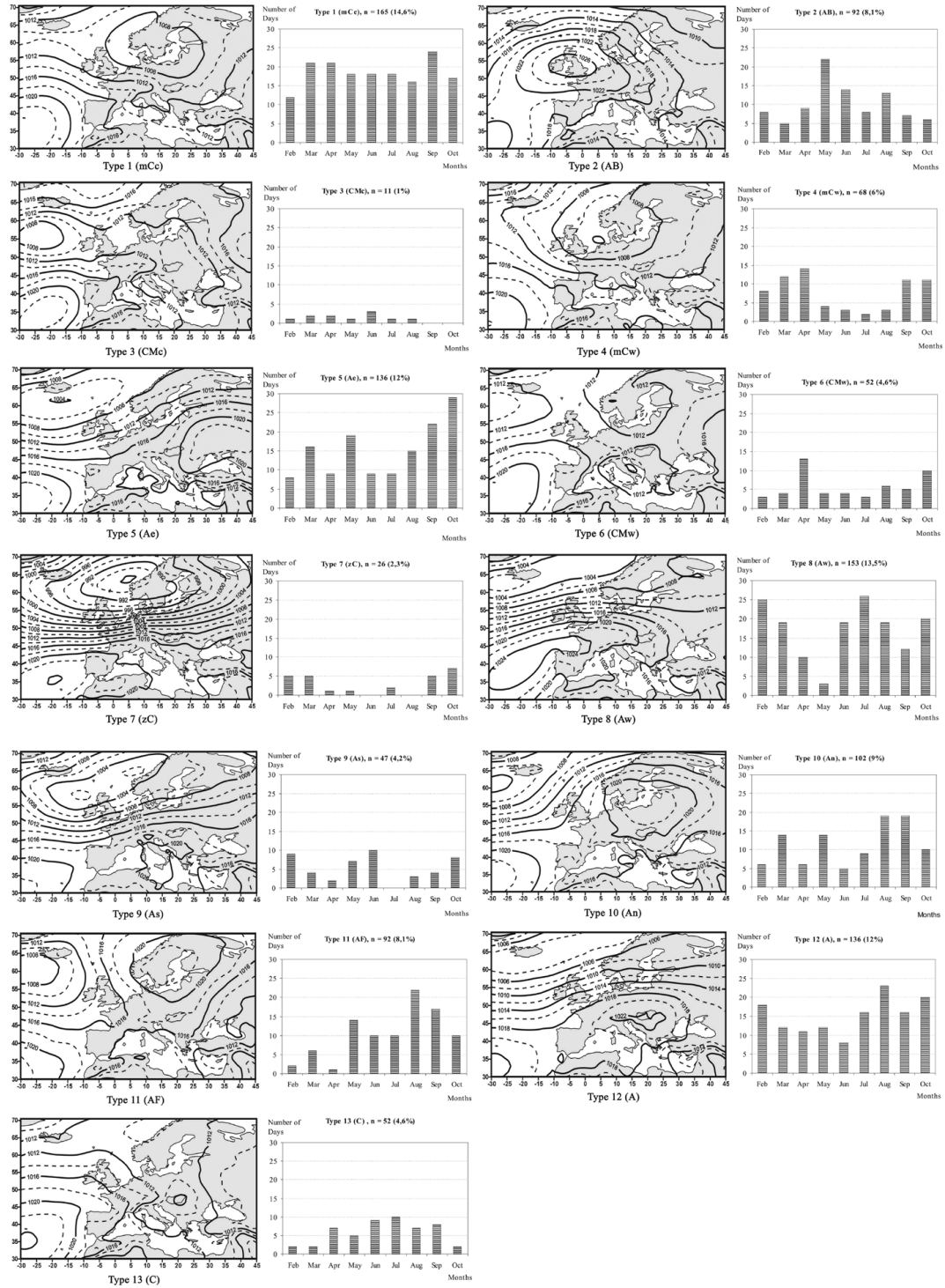


Figure 3.3: An example of circulation patterns from Peczel's classification (1997–2001; MAKRA et al., 2006).

PERRET's catalogue

The Swiss weather type classification was issued by Perret (PERRET, 1987) as a part of the Alpine Weather Statistics, a comprehensive characterization of the

regional synoptic situation in a circle with radius of 2° latitude centered at Switzerland. This is another subjective classification catalogue which resembles the Hess and Brezowsky classification, but modifies the hierarchy of atmospheric attributes to classify each day. The first criteria, the intensity and cyclonicity of the circulation within the target area, allow to distinguish types dominated by an upper level flow, by upper level highs and by upper level lows. The flow is subsequently divided into five flow directions, and characterized by being cyclonic or anticyclonic, leads to a total of 12 types. Upper level high and low groups are divided according to the position of the pressure centers on a second and third detail level, leading to 9 and 10 types respectively and a total of 31 types.

ZAMG catalogue

This catalogue has been supplied by the Central Institute of Meteorology and Geodynamics in Vienna (Austria), and focuses the Eastern Alpine region. It combines information about circulation patterns according to BAUR (1948) and LAUSCHER (1985) as well as 6 air masses at an upper level (< 850 hPa) and a surface level (> 850 hPa), and passages of surface fronts over the town of Vienna since 1950. This mass of information concluded into more than 80 different classes which were reduced to 43 classes for the *cost733* dataset.

3.2.2.2 Threshold based methods

The most relevant difference between subjectively defined types and their definition by thresholds is the formulation of explicit rules for the latter, which establish their types using quantitative thresholds or predefined rules for assignment, e.g. angles to delimit the precedence of an advection. The use of thresholds or explicit rules allows for automated classification, enhancing their reproducibility and fast processing, but there are still many subjective decisions during the process of predetermination of thresholds and rules. For that reasons some authors called them as hybrid or mixed.

GWT Grosswetter-types or prototype classification

The first example of a threshold based classification is a large scale circulation classification method which is inspired by the so called Grosswetter-types of HBGWT, and objectively classifies MSLP fields in terms of varying degrees of zonality, meridionality and vorticity (BECK, 2000; BECK et al., 2007, Fig. 3.4).

It is based on the similarity (in terms of pattern correlations) of daily patterns with three prototypical and ideal flow patterns (Fig. 3.5). The first prototype is a strict zonal pattern with values increasing from north to south; the second is a strict meridional pattern with values increasing from west to east and the third is a cyclonic pattern with a minimum in the center and increasing values to the margin of the field.

The degree of similarity between each daily field in the input dataset and those prototypes are measured by the calculation of Pearsons correlation coefficients

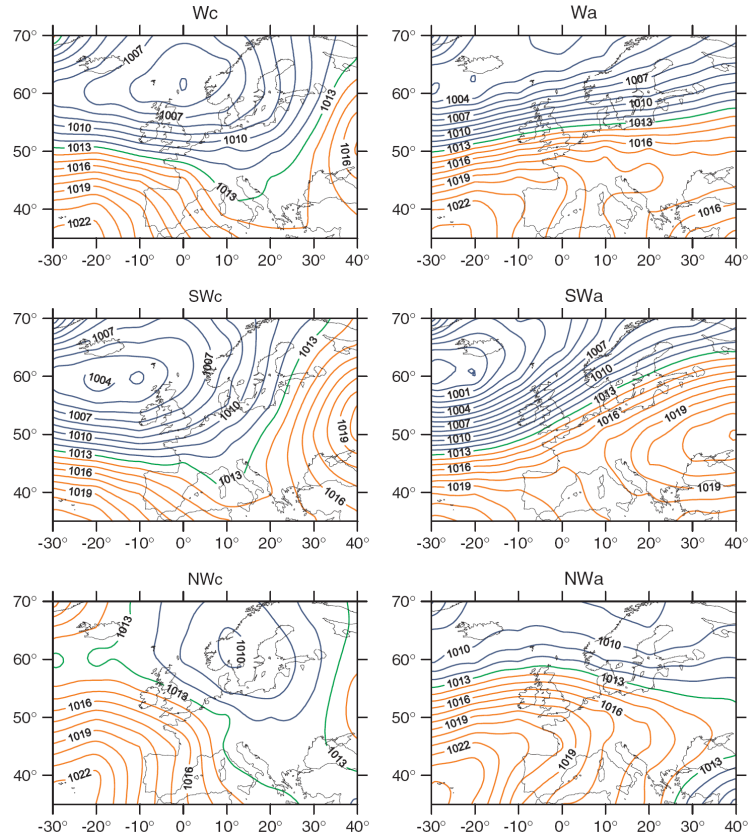


Figure 3.4: An example of circulation patterns derived from Grosswetter-types or prototype classification (from [BECK et al., 2007](#)).

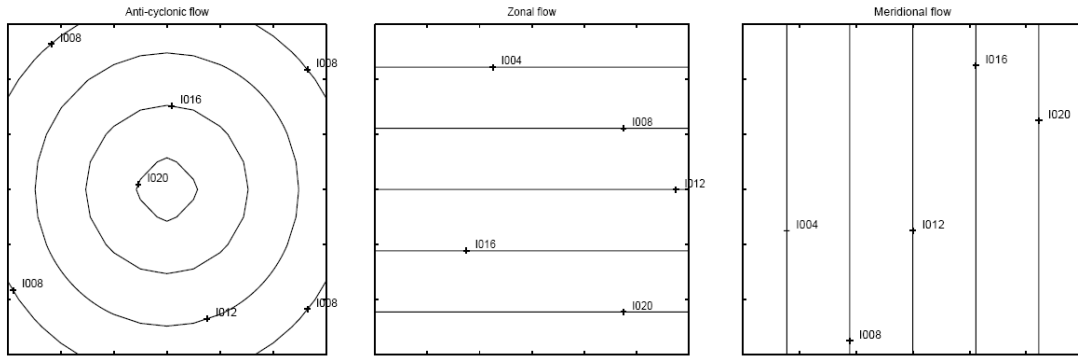


Figure 3.5: Idealized flow patterns: (anti-)cyclonic, zonal and meridional (from left to right).

of zonality (Z), meridionality (M), and vorticity (V) for each case (day). The main circulation types are then defined by means of particular combinations of these three coefficients. Assignment to central high and central low-pressure types results from a maximum V coefficient (negative and positive respectively).

There are a fixed numbers of combinations, thus only a set of numbers of types are possible. For 8 directional types the main wind sectors (N, NE, E, SE, S, SW, W, NW) are used, which are defined in terms of the Z and M coefficients

(e.g., $Z = 1$ and $M = 0$ for the W-E pattern, $Z = 0.7$ and $M = 0.7$ for the SW-NE pattern, and so on), and remaining cases are assigned to one of these types according to the minimum Euclidean distance of their respective Z and M coefficients from those of the predefined types. Two additional types for pure cyclonic and pure anticyclonic situations lead to 10 types and an indifferent type according to cyclonicity to 11 types. For 16 types the following numbers apply: 1 to 8 cyclonic, 9 to 16 anticyclonic and for 24: 1 to 8 cyclonic, 9 to 16 anticyclonic, 17 to 24 indifferent. Adding 2 or 3 cyclonicity types results in 18 or 19 and 26 or 27 types accordingly.

LWT2

H.H. Lamb created a subjective catalog for the British Isles ([LAMB, 1972](#)) in which the types are defined by the direction of air flow and (anti) cyclonicity, which can be downloaded from the Climate Research Unit of the University of East Anglia (www.cru.uea.ac.uk). In contrast to the Hess-Brezowsky catalog, the Lamb classification does not consider a limit on the duration of periods with the same type (at least 3 consecutive days in the former, except the unclassified days).

A initial objectification of the Lamb catalog was performed by [JENKINSON and COLLISON \(1977\)](#) using daily sea level pressure data on a regular 5 latitude by 10 longitude grid (16 grid points around the region of interest; Fig. 3.6), and acceptably reproduces the subjective Lamb weather types ([JONES et al., 1993](#)). The processes includes the calculation of several atmospheric indices from the original grid points, namely direction and intensity of flow as well as total vorticity, a measure of the rotation of the atmosphere [positive vorticity corresponds to a low pressure area (cyclonic) and negative vorticity corresponds to a high pressure area (anticyclonic)]. Each day's pressure pattern is summarized by different values of the westerly, southerly and resultant flow, as well as total vorticity. The circulation type is then determined according to vorticity-flow ratio thresholds, resulting in 8 pure directional types (e.g. W= West), 2 pure anticyclonic/cyclonic types (A, C) and one type denoted as undefined. Also, it is possible to obtain a total of 27 weather types: anticyclonic, cyclonic, 8 directional types, 16 hybrid types (e.g. ANE = North-East, partly anticyclonic), plus the undefined type.

The package COST733CLASS includes a modified version of the Jenkinson and Collison system ([JAMES, 2006](#)) that additionally allows to classify undetermined days and the vorticity and flow strength thresholds are adjusted so that exactly 33% of the days fall into each of the three vorticity classes anticyclonic, indeterminate and cyclonic. Additionally, some adjustments are done according to the relative grid-point spacing and the central latitude of the classification domain ([TANG et al., 2008](#)).

LIT (LITADVE/LITTC) – Litynski advection and circulation types

Litynski developed a classification scheme ([LITYNSKI, 1969](#)) based on the calculation of three indices from gridded MSLP data for the Polish region, to esti-

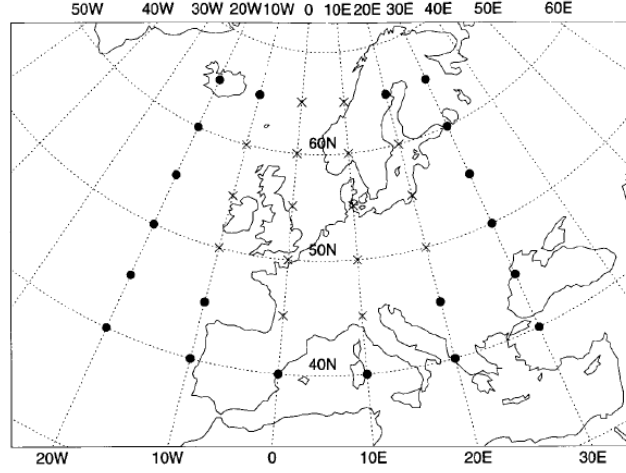


Figure 3.6: An example of grid points used for the allocation of weather types in the Jenkinson and Collison classification scheme (crosses) and the P27 scheme (solid dots and crosses) for The Netherlands, (from [BUISHAND and BRANDSMA, 1997](#)).

mate the advection of air masses as well as a cyclonicity characteristic ([PIANKO-KLUCZYNSKA, 2007](#)). The three indices are a meridional (W_p) and zonal (W_s) index, calculated as spatially averaged components of the geostrophical wind vector, while cyclonicity (C_p) is estimated as $P_{central} - 1000\text{hPa}$, where $P_{central}$ is the pressure at the central grid point for the domain.

Threshold values for these three indices are obtained for each day of the year utilizing the respective long-term means \bar{I} and standard deviations $sdev_I$ resulting in three categories for each index (negative, indifferent, positive), where the indifferent category includes all I for

$$\bar{I} - 0.433sdev_I \leq I \leq \bar{I} + 0.433sdev_I \quad (3.1)$$

approximating one third of the sample if normal distribution is assumed.

Circulation types are defined as distinct combinations of index categories for W_p and W_s , leading to nine advection types, characterized by the direction of advection (e.g., W_p = negative and W_s = positive for type NW). Including C_p , results in a further subdivision of directional types into 27 circulation types according to their cyclonicity characteristics (e.g. W_p = positive, W_s = indifferent and C_p = negative for a southerly cyclonic type).

WLK – Objektive Wetterlagenklassifikation

This method is based on the OWLK weather type classification by [DITTMANN et al. \(1995\)](#) and [BISSOLLI and DITTMANN \(2003\)](#), originally consisted of 40 different types. Criteria for defining the types are the dominant wind directions within the domains at the 700 hPa level as well as the cyclonicity of the geopotential height fields at 925 hPa and 500 hPa and the total precipitable water. Each day is denoted by a five digits code, the first two being the dominant wind (derived from U and V-components at 700 hPa) sector counting clockwise.

The third and fourth letter denote anticyclonicity or cyclonicity at 925 hPa and 500 hPa, respectively, based on the weighted mean value of the quasi-geostrophic vorticity, again putting higher weights on central grid points. The fifth letter denotes Dry or Wet conditions, according to a weighted area mean value of precipitable water (whole atmospheric column) which is compared to the long-term daily mean. For calculating the precipitable water the geopotential height, temperature and relative humidity at 955, 850, 700, 500 and 300 hPa are used.

The classification WKLC733 included in COST733CAT provides a few simplifications (see PHILIPP *et al.*, 2010): circulation patterns are derived from a simple majority (threshold) of the weighted wind field vectors at 700 hPa while the integrated precipitable water content is replaced by the towering water content. In order to achieve a classification system for 28 types (WLKC28) six main wind sector types are used (01 = 330–30° and so on in 60° steps) plus one undefined type, which are further discriminated by cyclonicity as described above. 18 types (WLKC18) are produced by using nine wind sector types (sector 01 = 345 – 15°, 02 = 15 – 75°, 03 = 75 – 105°, 04 = 105 – 165°, 05 = 165 – 195°, 06 = 195 – 255°, 07 = 255 – 285°, 08 = 285 – 345°, 00 = undefined) and cyclonicity at 925 hPa, while the latter is omitted for producing nine types (WLKC09).

SCHÜEPP – Alpine Weather Statistics

Although initially developed as a manual classification scheme (SCHÜEPP, 1957, 1968, 1979), explicitly focusing on the western Alpine region and Switzerland (spatial domain of 2° radius centered at 46.5°N, 9°E), this classification has been included within the threshold based methods because circulation types are defined by thresholds with regard to the following variables: surface pressure gradient and wind direction, 500 hPa wind direction and intensity, 500 hPa GPH, vertical wind shear and baroclinicity. The catalogue comprises three main groups: advective/convective types (characterized by pressure gradients above/below a certain threshold) and mixed types showing intermediate characteristics concerning horizontal and vertical dynamics and 40 subclasses.

3.2.3 Methods producing derived types

The classifications where both types and cases are defined and assigned by a numerical procedure are usually referred to as computer based, computer-assisted, automated, or objective classifications. The word “objective” does not imply a pure objectivity of the whole classification process because the procedures always involve some subjective decisions, and those decisions may considerably affect both the classification processes and the outputs. Even though the term “computer assisted” might be more appropriate, the term “objective” will be used here because of its simplicity and generally wider use. As in other sciences, a fundamental assumption on classifying circulation patterns is the existence of a certain, although unknown, organization or structure within the data. Several methods have been devised to find such structure and classify it in several groups:

1. The use of a multivariate reduction procedure called principal component analysis (PCA). Such methodology produces a set of new variables, which are labelled as principal components, explaining most of the variance of the input data. Afterwards, some measure of relation between the PCs and the original data is used to classify the data in different groups.
2. Another strategy consists of finding “typical” patterns and classify the whole dataset based on the degree of similarity of each map using some type of distance, called leader algorithm ([HARTIGAN, 1975](#)).
3. The third proposal is a combinatorial approach to optimize a partition according to a function, commonly the minimization of within-type variability.

3.2.3.1 PCA based methods

The PCA or EOF (Emprical Orthogonal Functions) approach was first introduced in fluid dynamics by [LORENZ \(1956\)](#), and has been widely applied in meteorology and oceanography studies since then [[PREISENDORFER \(1988\)](#), [JOLLIFFE \(2002\)](#)]. The objective of PCA is to provide a compact description of the spatial and temporal variability of data series in terms of orthogonal functions or “statistical modes”. Usually, most of the variance of the spatially distributed time series is in the first few orthogonal functions, whose patterns may then be linked to possible dynamical mechanisms. The potential of PCA to be used as a classification tool was suggested by [RICHMAN \(1981\)](#) and more deeply discussed and elaborated by [RICHMAN and GONG \(1999\)](#). The basic idea of using PCA as a classification tool consists in assigning each case to a PC according to some rule.

However there are several fundamentally different modes for PCA, serving to different purposes: either as a data preprocessing tool prior to cluster analysis (S-mode is such a case) or as a classification tool (in T-mode). In case of the most commonly used S-mode the scores are time series representing the most important types of data variability in time (“modes of variability”), while the loadings indicate the location and extend to which these time series are realized. Things are reversed in T-mode, where the scores describe important spatial patterns and the loadings reflect the amount of their time variant realization ([Fig. 3.7](#)).

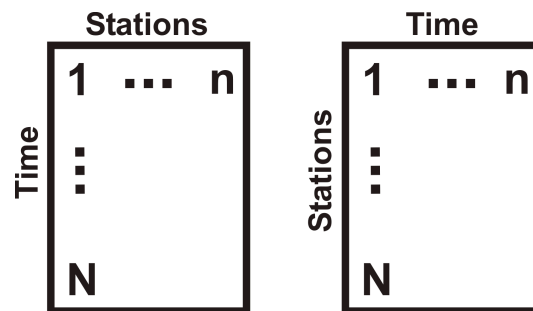


Figure 3.7: S-mode (left) and T-mode (right) decomposition matrix in a PCA.

TPCA – principal component analysis in t-mode

The classification of circulation patterns by obliquely rotated Principal Components in T-mode (also called TPCA, Principal Component Analysis in T-mode) as included in the data base is based on Huth [HUTH (1997); Fig. 3.8], while alternative implementations can be found from others authors (COMPAGNUCCI and RICHMAN, 2008).

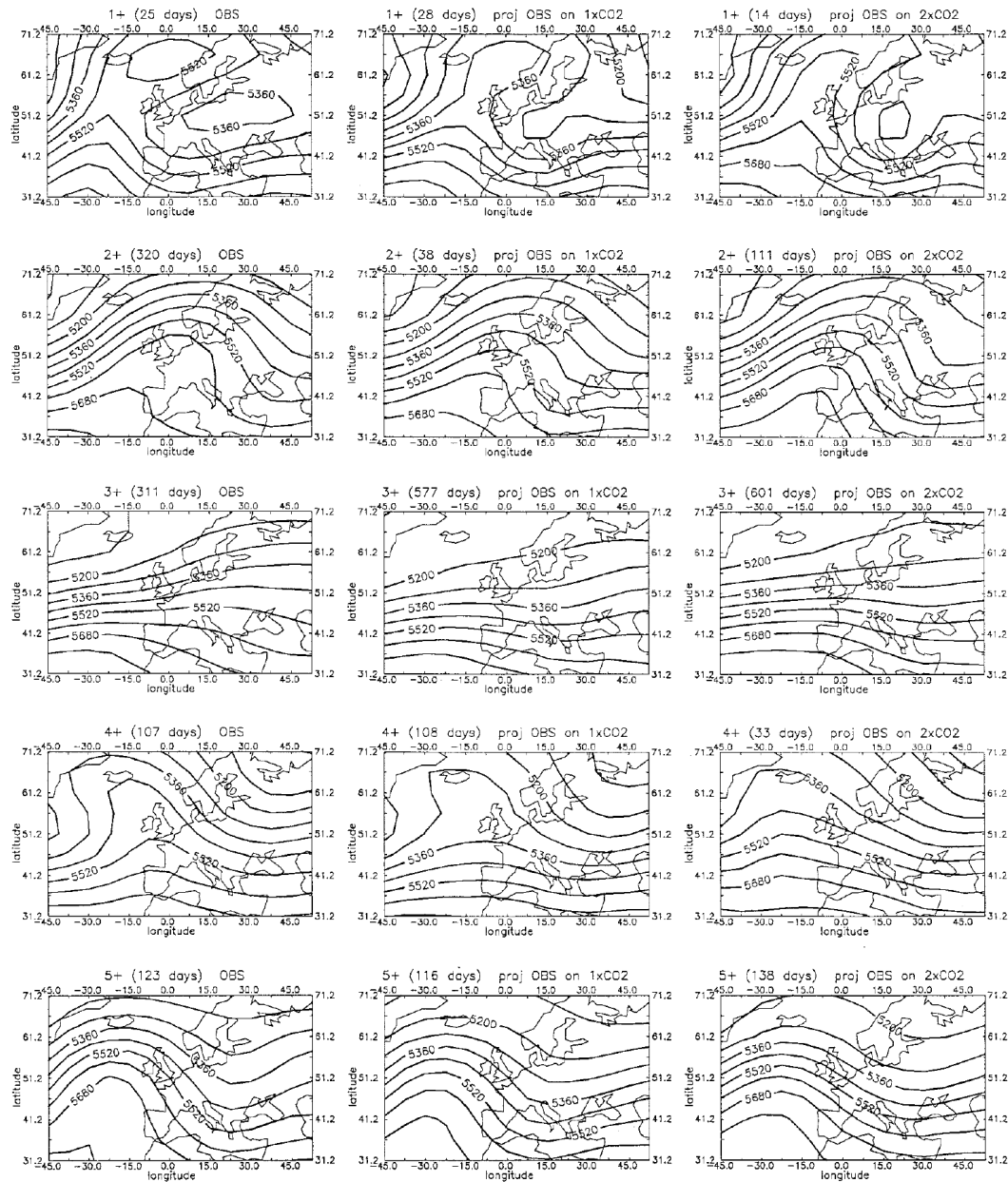


Figure 3.8: An example of circulation patterns generated by T-mode PCA (from HUTH, 1997).

The procedure follows several steps. First of all, the raw data are standardised spatially: each pattern's mean is subtracted from the data; then the patterns are

divided by their standard deviations. Secondly, the data is split into ten subsets: selecting the 1st, 11th, 21st, 31st, 41st, etc. pattern as the first subset; the 2nd, 12th, 22nd, 32nd, 42nd, etc. as the second subset, and so on. The reason of such splitting is to reduce the computer time and memory constraints, and to speed up the calculation of the PCA. Consequently, the principal components obtained for each subset are projected onto the rest of data by solving the matrix equation

$$\Phi A^T = F^T Z \quad (3.2)$$

where F and Φ are matrices of PC scores and PC correlations, respectively, Z is the full data matrix, and A are pseudo-loadings to be determined. In order to obtain a better solution, an oblique rotation (using direct oblimin) is applied, and each day is classified with that PC (type) for which it has the highest loading. Contingency tables between each subset's types (every subset solution is compared with the other nine ones) are finally used to compare the 10 classifications. The subset which gains the highest sum (of the nine comparisons) is selected, and it is selected as the final one.

The COST733CLASS software package offers the possibility to tell the program exactly how many types should be produced and supports this decision by printing the explained variances of the principal components.

P27 – Kruzinga empirical orthogonal function types

The P27 classification scheme is an objective scheme developed at the Royal Netherlands Meteorological Institute ([KRUZINGA, 1979](#)), but in contrast to T-PCA, uses the s-mode variant of PCA.

Originally, the P27 scheme used daily 500 hPa heights on a regular grid of 36 gridpoints, comprising nearly the whole of Europe. The actual 500 hPa height, h_{tq} , for day t at grid point q is reduced first by subtracting the daily average height, ht , over the grid, to remove a substantial part of the annual cycle. The pattern of each day P_{tq} ; are given by:

where N is the number of days. Subsequently, the vector of reduced 500 hPa heights is approximated as:

$$p_t \approx s_{1t}a_1 + s_{2t}a_2 + s_{3t}a_3, \quad t = 1, \dots, N. \quad (3.3)$$

where \mathbf{a}_1 , \mathbf{a}_2 and \mathbf{a}_3 are the first three principal component vectors and s_{1t} , s_{2t} and s_{3t} their amplitudes or scores. Instead of using the correlation or covariance matrix, the eigenvectors are calculated from the unadjusted (neither with regard to mean nor variance) product matrix.

The flow pattern of a particular day is thus described by three amplitudes instead of 36 grid-point values. It often turns out that $s_{1t}\mathbf{a}_1$ characterizes the east-west component of the flow, $s_{2t}\mathbf{a}_2$ the north-south component and $s_{3t}\mathbf{a}_3$ the cyclonicity (or anticyclonicity).

Using the first three principal components, the classification scheme is developed as follows. The range of each amplitude is divided into three equiprobable intervals.

Then each pattern is, on the basis of its amplitudes, uniquely assigned to one of the $3 \times 3 \times 3 = 27$ possible interval combinations. However, varying numbers of classes can be achieved by defining different numbers of amplitude intervals (e.g. $3 \times 3 \times 2 = 18$ classes).

PCAXTR – principal component analysis extreme scores

This method is an objective way for obtaining the number of circulation types and its initial centroids, by using orthogonally rotated (method Varimax) scores time series of PCA in s-mode (ESTEBAN et al., 2005, Fig. 3.9). Essentially, it tries to mimic the T-mode PCA approach, that uses the coefficients obtained with PCA (correlations) for distributing the cases among the different groups considered. PCAXTR employs the PC-scores, which represent the degree of representativeness of the PC loadings' pattern with respect to the original data, to do this assignment, reducing substantially the calculation requirements of the former. Thus, they can be utilized to establish the number of circulation types of the classification as well as its centroids. As well as, T-mode PCA, it also applies a rotation (in this case an orthogonal VARIMAX rotation) to obtain loadings patterns which are independently closer to real anomaly patterns than unrotated loadings and therefore include a physical meaning.

The general procedure does not vary too much with respect to the usual outline of PCA: S-mode structure (gridpoints as the columns and cases as the rows of the matrix), use of the correlation matrix to obtain the new variables, but include a spatial standardization of the gridded data before the PCA procedure. After applying PCA, the use of the extreme scores rule criterion, which by being fulfilled or not by each original case, leads to the final number of classes and their centroids.

For each PC and phase (positive or negative) those cases that according to their scores show a spatial structure similar to some rotated PC (e.g. cases presenting high absolute scores with values above 2 or below -2, while at the same time having low values – between +1 and -1 for the rest of the PCs) are selected and become the centroids for each component and phase (positive/negative) by averaging their score values. The idea behind this selection is that this small subsample of observed cases (usually 2.5–5% of the sample size) is very well represented by one of the PCs and that this PC is exclusively representative for these cases due to the orthogonal rotation. In other words, the mode of spatial variation represented by the components reflects at least one case in reality and is not an artefact due to statistical forcing of the PCA. This further implies that the potential number of classes will be twice the number of PCs retained (counting the positive and negative phases). This total can be reduced if any of these possible types does not have any observed cases assigned to it, according to the extreme scores criterion, therefore being discarded as an artefact of the PCA procedure.

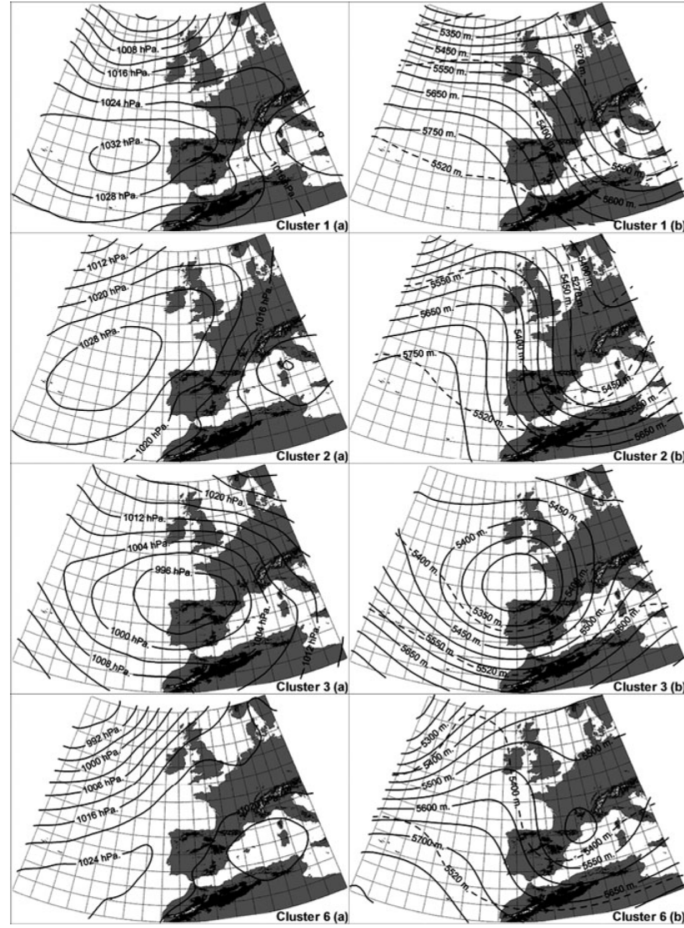


Figure 3.9: An example of circulation patterns generated by PCAXTR (from [ESTEBAN et al., 2005](#)).

The rest of the data are finally classified using the shortest Euclidean distance (without any further optimization). This is calculated using the multivariate coordinates of each class expressed by its scores, and the location in the PC space of the centroid of each class.

Some versatility is introduced by the use of a similarity threshold based on the PC-scores (normally $-2/+2$), thus the suitability of this threshold value depends on the variability of the sample. The normally used $-2/+2$ can be inappropriate for samples with very few cases or with little variability, being recommendable to change to, for example, a $-1/+1$ threshold.

3.2.3.2 LDR – leader algorithms

These methods seek for key (or *leader*) patterns in the original data, which are located in the center of high density clouds of entities (days) within the multidimensional phase space spawned by the variables, i.e. grid-point values. They use the Pearson correlation coefficient or sums of squares of differences as similarity metrics, although other metrics could be implemented, and a certain threshold of such metric for definition of another observation being similar.

Those methods were established at a time when computing capacities have been available but were still limited, and their main disadvantage is their tendency to produce a “snowball effect”, e.g. one huge group accompanied by many small ones and, depending on the variant of the method, even many individual unclassified cases. On the other hand, they may yield a good separation between clusters.

LUND – classical leader algorithm

The origin of the Lund’s methodology is an automated classification scheme based on pattern correlations to identify frequently appearing, well separated SLP patterns over the northeastern USA. Originally, the procedure followed several steps. First, Pearson correlation coefficients between all days are calculated and for each observation the number of cases being more similar to it than a similarity threshold ($r > 0.7$) is counted. The first key pattern (*leader*) is defined as the day with the largest number of correlation coefficients $r > 0.7$. This day and all days with correlation coefficient $r > 0.7$ to that key day are then removed from the dataset. On the remainder data the search for the second and following leaders is performed in the same manner, until all types (of the predefined number of types) have a key day. Finally all days are just assigned to a key day according to the highest correlation coefficient, regardless of which key day they had been assigned initially.

Some modifications have been included into the COST733CLASS package. Although in COST733CLASS package the default threshold is a correlation coefficient of 0.7, in the second each case is assigned to the class of the nearest (most similar) leader (regardless of any threshold). Thus in contrast to the original there are no unclassified cases.

KH – Kirchhofer types

The Kirchhofer-method ([KIRCHHOFFER, 1974](#)) has been considered a variant of the Lund method, using the squared distances between normalized grid-point values as a metric for dissimilarity between the maps. Thus, two patterns were allowed to be classified as similar only if the so-called Kirchhofer score (see below) was high enough.

The similarity measure, called Kirchhofer Score, is the minimum of all correlation coefficients calculated for each row (latitude) and each column (longitude) of the grid separately and the overall correlation coefficient. This idea was also recommended by [YARNAL \(1993\)](#), who suggested that the columns and rows of the grid could serve as sub-domains, and [BLAIR \(1998\)](#), who replaced the squared distances with, equivalent, linear correlation coefficients between map patterns. This procedure should make sure that two patterns are similar in all parts of the map.

Since this distance measure is considerably lower than the usual pattern correlation coefficient, the threshold for finding key patterns has to be smaller too, and a typical value which is used for COST733 is set to 0.4, but the researcher might change it using the COST733CLASS software package.

ERPICUM (ESLP/EZ850) – Erpicum and Fettweis

This classification algorithm is similar to LUND, in the sense that the final classification of the days is based on their initial assignment to a key day, differing, however, by the calculation and use of the similarity measure (FETTWEIS *et al.*, 2010, Fig. 3.10). Another difference is the omission of the final step and the inclusion of a new procedure (varying the threshold) to avoid large dissimilar class sizes. Finally, the original method was intended only for the classification of 500 hPa geopotential or sea level pressure patterns, but the COST733CLASS software makes possible to apply it to other variables as well, or even multi-field data-input is available.

At the beginning of the process of classification, the data are standardised temporally, providing the same weight for all grid points of the input maps. Later, a similarity index I for each pair of days is computed.

Then, for each pair of days the similarity index, I :

$$I(day_1, day_2) = 1 - \frac{1}{2} \cdot \sum |Z(day_1) - Z(day_2)|. \quad (3.4)$$

is calculated, where $Z(day)$ is the vector of normalized pressure values for one day. If one day is very similar to another, this couple of days will achieve an index of approximately 1.0. If two days are very different, their index will be set to around 0.0 (in case of multi-field data-input, the daily mean of all the input variables is taken). Departing from LUND (1963) the distance threshold for the determination of key patterns, ic , is progressively decremented, starting from 1 and being reduced by a factor epsilon, ϵ , for each type, i.e.

$$ic(k) = 1 - \epsilon \cdot k, \quad k = 1, \dots, n, \quad (3.5)$$

where k is the number of the class and n is the maximum number of types. The whole classification scheme (see above) is iteratively applied for different values of ϵ in order to optimize the skill score (percentage of explained variance BUSHAND and BRANDSMA, 1997). For each run ϵ is increased by

$$\epsilon = 0.05 \cdot (j - 1), \quad j = 1, \dots, m, \quad (3.6)$$

where j is the number of the iterative run and m is the maximum number of runs. Thus, compared to the LUND (1963) classification this procedure is considerably more time demanding, but on the other hand includes a mechanism for reducing within-type variability.

3.2.3.3 Classification based on clustering algorithms

Cluster analysis is a mathematical methodology designed to find natural inherent clusters in a data set hence it is the most commonly used approach for classifying circulation patterns. Scientific literature shows a great variety of algorithms, although a subdivision between hierarchical and non-hierarchical (sometimes known as optimization) algorithms is accepted, both present in the COST733CLASS software.

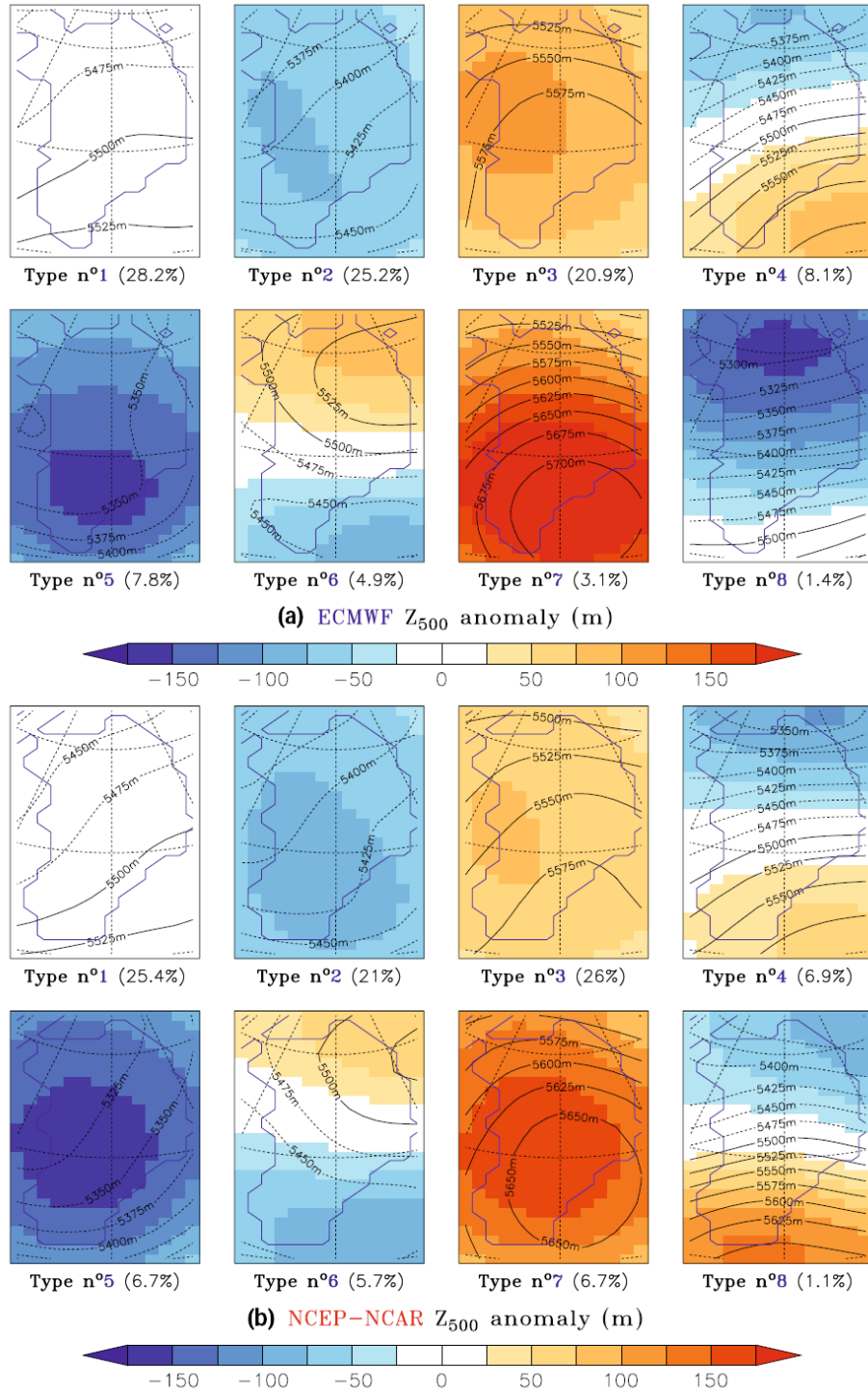


Figure 3.10: An example of circulation patterns in Greenland generated by ERPICUM (original in [FETTWEIS et al., 2010](#)).

Hierarchical clustering

Hierarchical cluster analysis can be realized in two opposite ways. Divisive algorithms begin with the whole set and proceed to divide it into successively smaller

clusters. The most common, however, is the agglomerative clustering: each element begins as a separate cluster and is merged into successively larger clusters. This sequence finally will form one cluster containing all cases, so the process should be stopped at one step that would maximize the level of dissimilarity between groups according to a predetermined criterion (Fig. 3.11).

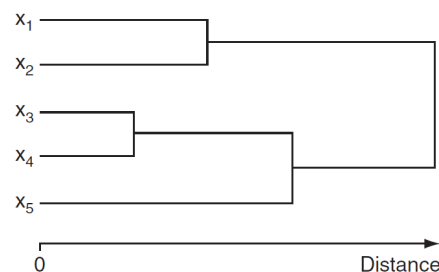


Figure 3.11: General procedure of a hierarchical (agglomerative) clustering, illustrated by a dendrogram. The distance vector at the bottom denotes the distance between the two combined clusters at each step respectively (WILKS, 1995).

Several hierarchical clustering algorithms have been used in climatology, the average linkage and Ward methods, having gained the widest popularity, the second being most often used because it reduces the overall variance. A comparison between them was performed by KALKSTEIN et al. (1996) for the classification of weather types, and by GONG and RICHMAN (1995), for regionalization. GONG and RICHMAN (1995) also evaluate different methodological choices, such as the distance measure and determination of preliminary cluster centroids. For example, it was obtained that average linkage is susceptible to produce the snowballing effect, that is, forms one huge cluster to which more and more other groups are attached in later stages of the clustering, accompanied by small clusters and unclassified days.

For the COST733 dataset no classification relies solely in a hierarchical algorithm (PCACA only uses Ward's method to create the initial seeds), but several ones have been implemented in COST733 software:

1. Ward's minimum variance method
2. single linkage
3. complete linkage
4. average linkage
5. McQuitty's method
6. Median (Gower's) method
7. Centroid method

3.2.3.4 Optimization methods

Optimization methods (or non-hierarchical clustering algorithms) are combinatorial approaches to arrange a set of objects (days) within groups (or clusters) which utilizes an optimization criterion to find a suitable partitioning of the data set. The optimization criteria usually is the minimization of the within-type variability measured as the overall sum of the Euclidean distances between the member objects of a type and the average of that type (centroid) which is equivalent to the sum of distances among all objects. Non-hierarchical algorithms offer some differences compared to the hierarchical ones. They allow for reallocation of objects, which might have been mis-grouped earlier, until no further improvement occurs in the criterion value. Non-hierarchical algorithms need the number of types to be determined a priori, tend to produce relatively equal-sized groups, and usually result in lower within-type variability, compared to other methods.

The majority of optimization methods included in the COST733CAT dataset is based on the k-means clustering algorithm (MILLIGAN, 1985) and uses the Euclidean distance as metric to measure the degree of similarity. K represents the number of clusters (types or classes) which should be derived, whose number must have chosen by the researcher, and *Means* denotes the average of all objects (e.g. daily pressure fields) within each cluster, which is called the centroid, and plays a fundamental role for this algorithm, whose principle is quite simple (Fig. 3.12). It begins with a so called starting or initial partition, usually selected by random, i.e. each object (daily pressure map) is assigned to a cluster by random, but it is possible to supply pre-determined seeds. The algorithm evaluates whether they are located within the most similar cluster; if there is a centroid being more similar for the object in question than the one of the current cluster (in terms of the Euclidean distance between the object and the centroid of the cluster), the object is shifted and the centroids of the old cluster and of the new cluster are recalculated in order to reflect the change in the membership. This recalculation can place some of the objects, previously checked, in the wrong cluster, due to the change in the centroids. Therefore all objects have to be checked again in the next iteration. This process keeps going on until, at some point in the process, all objects are assigned to their nearest cluster and no reassignment is necessary and possible anymore, i.e. convergence to an optimum is reached. However, as it is a heuristic algorithm, there is no guarantee that it will converge to the global optimum, and the result depends on the initial clusters. As the algorithm is usually very fast, it is common to run it multiple times with different starting conditions.

The most important difference between the optimization methods included in COST733CLASS software is how the starting partition is constructed, how the data is preprocessed and that there are different optimization algorithms than k-means although more or less related to it.

KMN: kmeans – conventional k-means with random seeds

This is the classical method of clustering with k-means, but includes a routine to select the best solution in terms of explained cluster variance (ECV) out of a

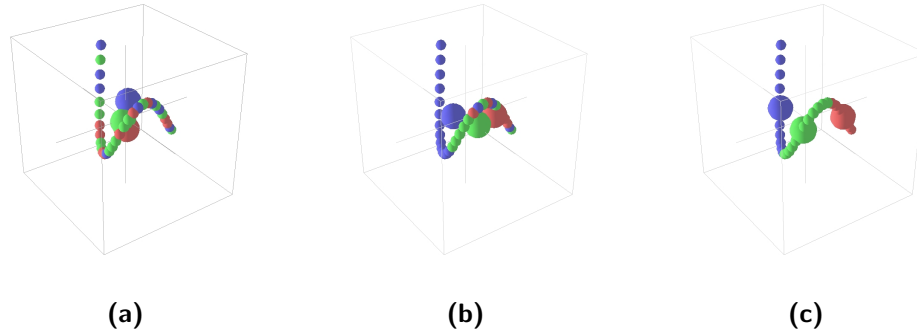


Figure 3.12: General procedure of an optimization clustering. Small spheres denote data points in a 3-dimensional phase space, colors denote assignment to one of three classes, large spheres denote class centres (centroids) according to the given partitioning. a) initial state of randomly partitioned data points, b) intermediate state with reduced within-type distances between data points, c) final optimization state with minimized within-type distances.

number of runs. K-means is a potentially unstable method, because it can obtain different solutions (optimized partitions) if different random starting partitions are used, and the existence of local optima in the minimization function (reducing the within cluster variance). In order to minimize such drawback, the routine by default reproduces the whole process 1000 times (which can be changed) and chooses the best solution.

CKMEANS – k-means by dissimilar seeds

Here the starting partition is created by selecting very dissimilar seeds (ENKE and SPEKAT, 1997; ENKE et al., 2005, Fig. 3.13). As in k-means, the initialization takes place by randomly selecting one object (pressure map) for the seed of the first cluster. The seeds of the remaining clusters are the selected to maximize the sum of differences between the seeds.

The most different object to the first one becomes the seed for the second cluster, while the seed for the third cluster is the object with the highest sum of the distances to the first two seed-patterns, and so on, until every cluster has one seed-pattern.

In a stepwise procedure the starting partition, initially consisting of the k seed-patterns, becomes the final solution when the remaining days are assigned to their most similar class. With each day entering a class, the centroid location is re-computed because a position shift of the object takes place in the n -multidimensional space (n being here the number of grid points).

After the initial assignment of all days has been performed an iterative k-means clustering process is launched; with each pass, members of the clusters are exchanged in order to improve the separation of the classes and their compactness. As a consequence the distance between class centroids continually decreases while the variability within the individual classes of the starting partition increases, but

..... 3.2 Description of classification methods

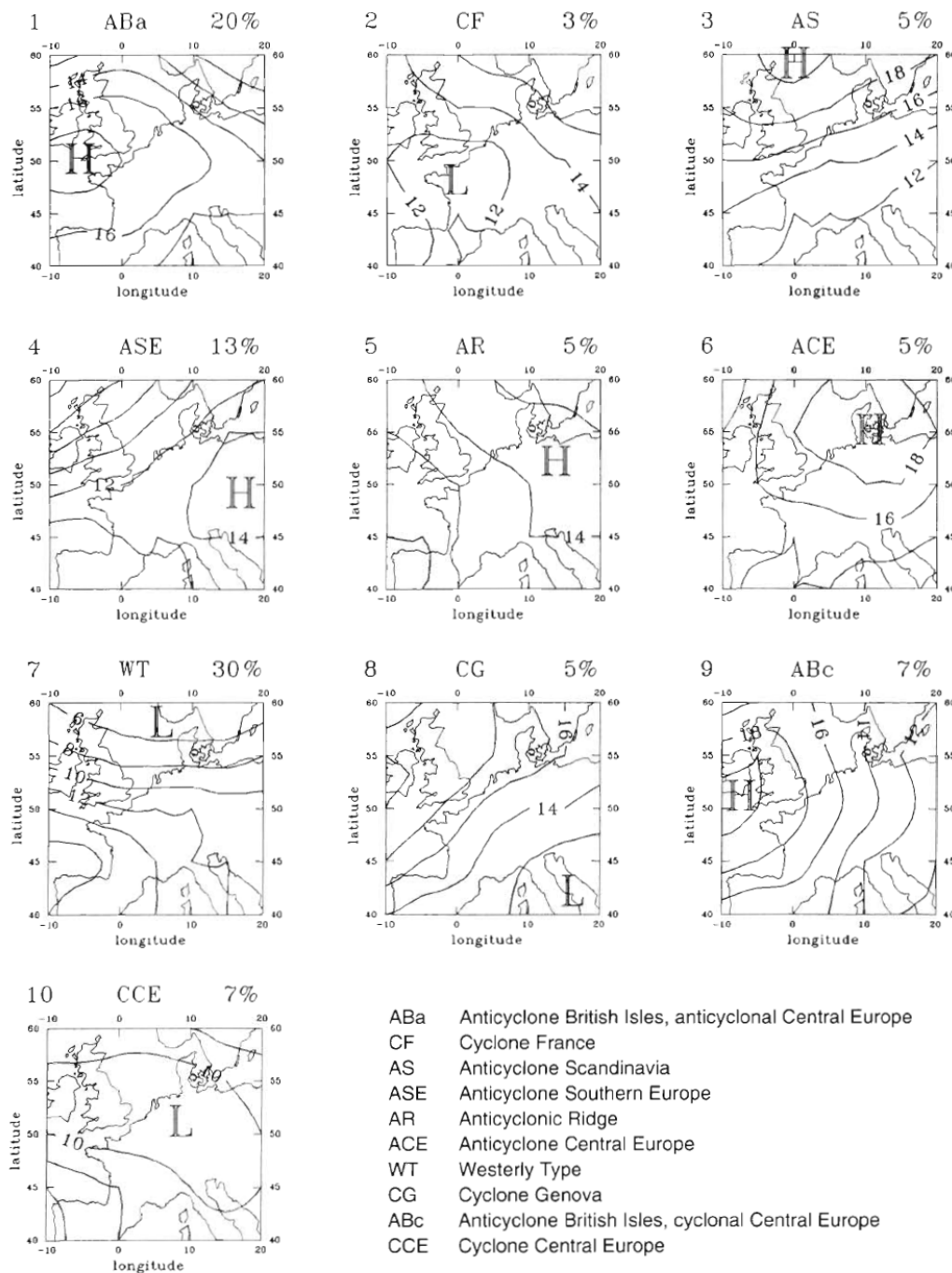


Figure 3.13: An example of circulation patterns in Central and Western Europe generated by CK-MEANS, (from [ENKE and SPEKAT, 1997](#)).

the whole processes will be stopped if two successive iterations leaves the contents of the classes unchanged (as in usual k-means), but only if they do not fall short of a certain number, e.g., 5% of all days. Otherwise the class is removed and its contents distributed among the remaining classes. Finally, the centroids converge towards a final configuration which has no similarity with the starting partition.

DKM – dkmeans

This is an alternative approach to the CKM method, although it differs in two aspects. First of all, the minimum of the distances to the preceding seeds is used for finding dissimilar seed patterns for the 2nd and further clusters, and not only the sum of the distances. Besides, there is no size restriction for the clusters: if the population temporarily decreases below 5% of the total sample size, it is usually filled up again later during the iterations. Thus this method is identical with k-means, however defines the starting partition with the most *different* objects (therefore the D in its name)

KMD – k-medoids - partitioning around medoids

The k-medoids algorithm is a classical partitioning technique that clusters the data set of n objects into k clusters where the number of clusters k again is set a priori. Like k-means, it is a partitional algorithm (breaking the dataset up into groups) and tries to minimize the squared error or Euclidean distance between points labelled to be in a cluster and a point designated as the center of that cluster. In contrast to the k-means algorithm, k-medoids chooses datapoints as centers (medoids or exemplars) and does not calculate the arithmetic mean. A medoid can be defined as the object of a cluster, whose average dissimilarity to all the objects in the cluster is minimal i.e. it is the most centrally located point in the given data set.

The algorithm selects k objects by random to become the initial cluster centers (medoids) and assigns all other objects to them according to the minimum distance. Next it calculates the cost function, which is the sum of the distances between each object and its nearest medoid. After that an iterative process begins where in each pass all objects (days) are checked to be a better medoid of a cluster. If this is the case the partitioning will be updated and the search for better centroids resumes. Finally, if no enhancement is possible by changing the medoids the process has converged to an (local) optimum.

PCAXTRKMN – k-means using PCA derived seeds

This variant of k-means uses a starting partition (number of groups and centroids) determined by the “extreme scores” criteria defined above; for that reason, the number of types is restricted (ESTEBAN et al., 2006, Fig. 3.14) compared to other methods of defining a starting partition.

CAP PCACA – k-means by seeds from hierarchical cluster analysis of principal components

This methodology essentially classifies the data set combining hierarchical (Wards algorithm) and afterwards non-hierarchical (k-means) clustering [YARNAL (1993); RASILLA ÁLVAREZ et al. (2010); Fig. 3.15]. An initial solution is obtained from the application of the hierarchical algorithm, serving as starting partition for the

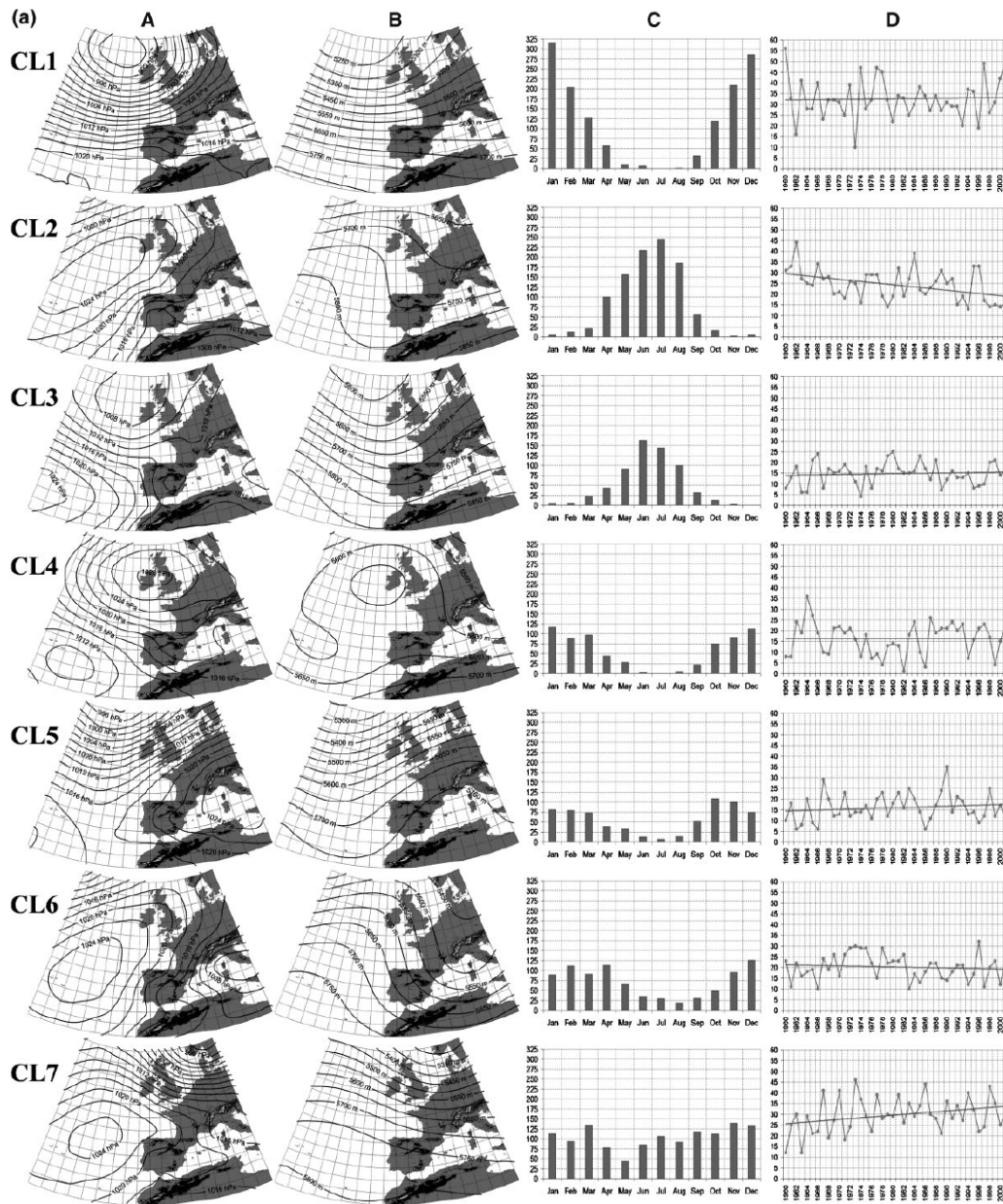


Figure 3.14: An example of circulation patterns generated by PCA_{XTRKMN}, (from [ESTEBAN et al., 2006](#)).

subsequent k-means procedure. However, not the raw original data are used for clustering; instead, they are submitted to a high-pass filtering to remove the seasonal cycle and a s-mode PCA to remove the co-linearity of the input variables. Thus the impact of variables (grid points) which are strongly correlated to a high number of other variables is reduced compared to the rest. Since only the first few components are retained PCA reduces the number of variables and therefore simplifies the numerical calculations. However, the main important effect might be the reduction of noise by discarding lower-ranking PCs.

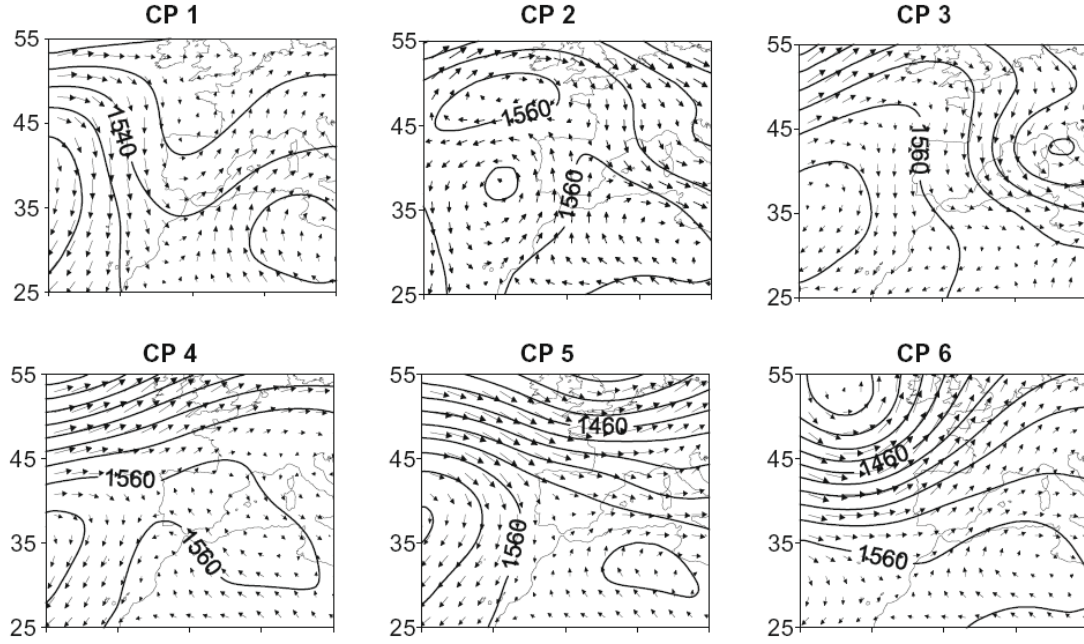


Figure 3.15: An example of circulation patterns generated by PCACA (from [RASILLA ÁLVAREZ et al., 2010](#)).

PETISCO – leader algorithm with optimized key patterns

This method represents a hybrid between the leader algorithm types and the optimization procedures, including an iterative optimization procedure to find optimal leading centroids ([PETISCO et al., 2005](#)). As for LUND, key patterns are identified among all days but the threshold used for the pattern correlation is higher, 0.9. In case of using more than one atmospheric level (originally both the MSLP and 500 hPa GPH fields were used) r is the minimum of the correlation coefficients calculated separately for each level. In contrast to the leader algorithm the key pattern is calculated as the centroid of the so called key group that consists of the key day and all days strongly correlated to it ($r > 0.9$). Iteratively the calculation for the key group centroid and the search for new members of the key group is repeated, until optimized key patterns exist, i.e. they do not change anymore. Thus the key group is optimized in terms of maximum member quantity. From these key groups the largest are selected as final types and all remaining days are assigned to these according to their maximum correlation coefficient.

SANDRA – simulated annealing and diversified randomization clustering

SANDRA is a non-hierarchical cluster analysis method, but it tries to find the global optimum which usually means better solutions than conventional k-means (see e.g., [PHILIPP et al., 2007](#); [FEREDAY et al., 2008](#)). The heuristic procedure of SANDRA allows temporarily adverse assignments to a class depending on a probability, P , high at the beginning but slowly decreasing during the optimization process, which might lead to an overall improvement of the classification,

minimizing the instability of the k-means technique, which is demonstrated by the dependence of the classification output on the preliminary selection of centroids (Fig. 3.16).

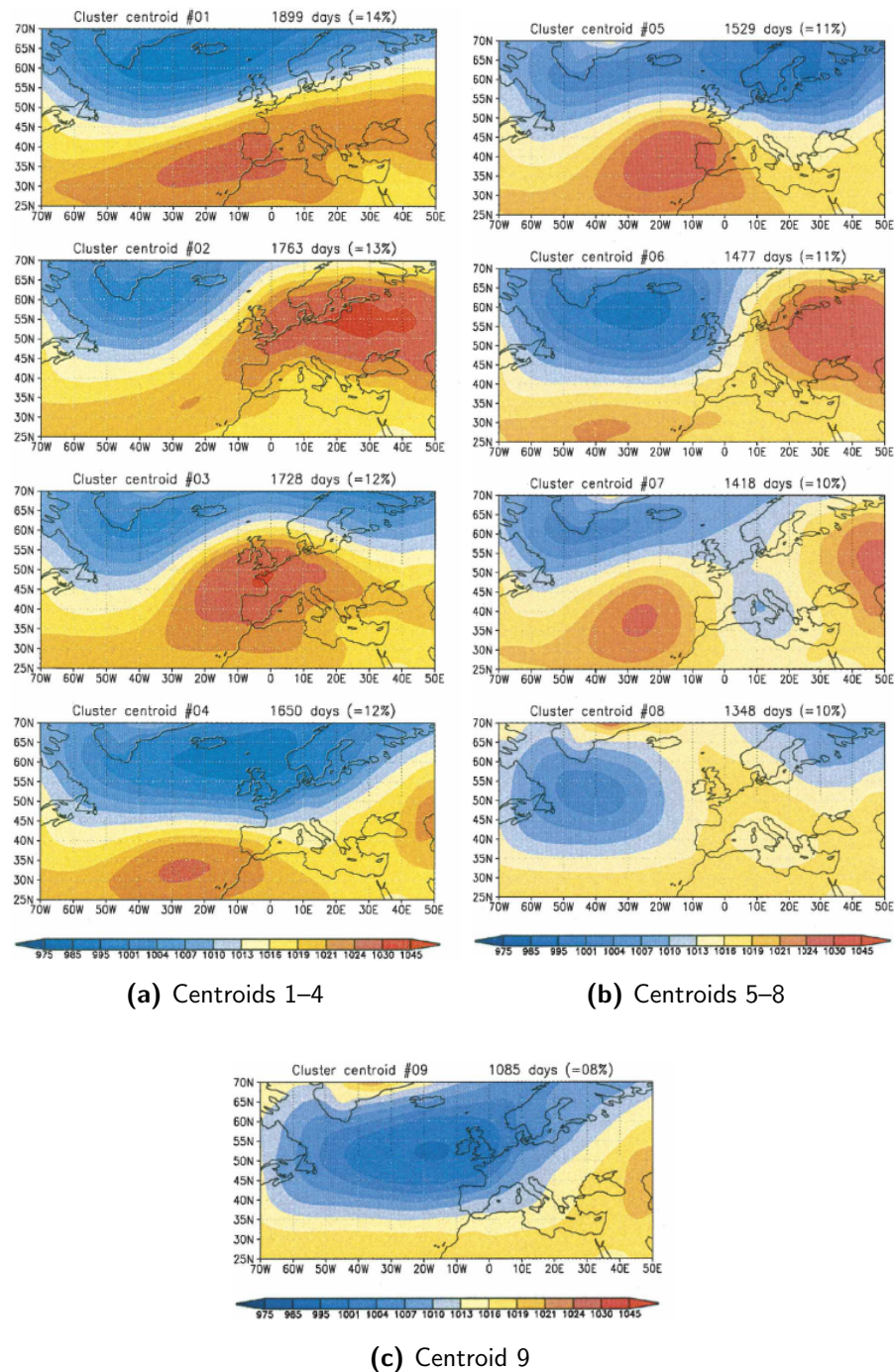


Figure 3.16: An example of winter-season (DJF) circulation patterns generated using the SANDRA scheme, (from PHILIPP et al., 2007).

In order to slowly reduce P a control parameter T (for temperature) which is a huge number at the beginning, is stepwise reduced by a cooling factor C (e.g., $C = 0.999$) in each iteration:

$$T = T \cdot C \quad (3.7)$$

P is then calculated as

$$P = \exp \frac{D_{current} - D_{new}}{T} \quad (3.8)$$

where $D_{current}$ is the Euclidean distance of the object to its current cluster and D_{new} the distance to a potentially new cluster. During the classification, a adverse or *wrong* re-assignment occurs when a random number r ($0 < r < 1$) is lower than P ; finally convergence occurs when the value of T is very low. Since the SANDRA classification procedure is time consuming, a relatively low cooling factor ($C = 0.999$) is used to speed up the run time, leading to a quick convergence but repeats the whole process 1000 times with randomly diversified starting partitions and a randomized scheme for object and cluster ordering. The best solution, according to within-type variance, is selected from these 1000 trials. Several diversifications of the original SANDRA algorithm are also included in COST733CLASS. They are the following:

1. *SANDRAS* consists essentially on the classification of sequences of consecutive days (in this case 3 days) using SANDRA, in order to reproduce the dynamics of the atmospheric movement ([PHILIPP, 2008](#)).
2. *SAT* corresponds to the acronym of “time constrained simulated annealing and diversified randomization” ([JOLLIFFE and PHILIPP, 2010](#)). This is an alternative method of analysis in which the classical Euclidean distance, that measures the degree of similarity between two objects, is weighted by a factor reducing the dissimilarity between two patterns if they are close together on the time axis.

NNW/SOM – neural network self-organizing feature maps

Neural networks represent an alternative group of classification algorithms besides non-hierarchical cluster analysis. The most popular neural network method proposed for the classification of weather patterns is the Kohonen’s self-organizing maps algorithm [SOMs; see e.g., [MICHAELIDES et al. \(2001\)](#); [MICHAELIDES et al. \(2007\)](#); [TYMVIOS et al. \(2010\)](#); Fig. 3.17].

Self organizing maps describe a way to arrange types defined by their features (grid point values) in a structure where similar types are adjacent to each other (a map). The classification by SOMs consists of a two-dimensional array of maps portraying typical patterns, with the most dissimilar pairs of patterns being located at the opposite ends of the main diagonals. SOM attempts to find points in the physical space that are representative of nearby observations, and it is not primarily concerned with grouping data. Besides, SOM network has the ability to learn without being shown correct outputs in the sample patterns (unsupervised) and is able to separate data into a specified number of categories with only two

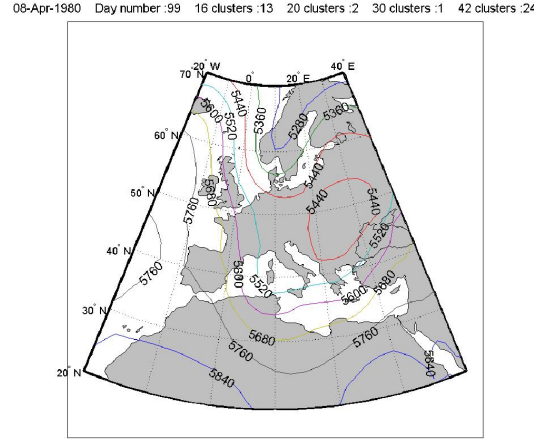


Figure 3.17: An example of a synoptic circulation pattern produced by a SOM, (from [Tymvios et al., 2008](#)).

neuron layers: an input layer and an output layer, the latter consisting of one neuron for each possible output category.

The objective is to discover significant features or regularities in the input data $X^{(k,j)}$; $k = 1, 2, \dots, p$; $j = 1, 2, \dots, M$ where k is a day and p is the total number of days and j is a grid point and M the total number of grid points. The input vector $X(p)$, representing a pressure pattern, is connected with each output neuron through weights $w(j)$, $j = 1, 2, \dots, M$ which are randomly chosen at the beginning. The output neuron whose weight vector is most similar to the input vector X is the so called winner neuron. The weight vector of the winner neuron, as well as those of its neighbourhood neurons, are updated to become more similar to the input pattern following the learning rule:

$$W_i^{(new)} = \begin{cases} w_i^{(old)} + a \left(X - w_i^{(old)} \right), & i \in n(I, R) \\ w_i^{(old)}, & i \in n(I, R) \end{cases} \quad (3.9)$$

where the neighbourhood set $N(I, R)$ of neuron I , within radius R consists of the neurons $I, I \pm 1, \dots, I \pm R$, assuming these neurons exist, with the maximum adjustment being around the winner I and decreasing for more distant neurons in terms of the distance within the (hexagonal) network topology.

The coefficient a in the above relationship is called the learning factor and decreases to zero as the learning progresses.

Also the radius R of the neighbourhood around the winner unit is relatively large to start with, so as to include all neurons and is consecutively shrunk down to the point where only the winner unit is updated ([Kohonen, 2001](#)). When all vectors in the training set were presented once at the input (one epoch), the whole procedure was repeated for 2000 iterations. In the end, this algorithm organizes the weights of the two-dimensional map, so that topologically close nodes become sensitive to input that is physically similar.

These networks are extremely demanding as far as computing power and memory is concerned. Likewise NNW does not converge to an optimum since its iterations were limited to 2000 here.

3.3 Development and history of the cost733cat database

3.3.1 Introduction

The purpose of the WG1C sub-group was to analyse the list of WTC methods and catalogues, which were gathered in WG1A via the WTC questionnaire returns, and select an optimal set of WTCs which will be studied in detail in the subsequent working groups of COST733. The selected WTCs should span various approaches to the problem of synoptic type classification, including cluster analyses, PCA, neural networks, objectivized versions of manual schemes and, where possible, digitized subjective-manual classifications.

Fully objective methods such as PCA and cluster analysis, generally yield sets of synoptic patterns which are not pre-determined before the method is applied. Such methods can be considered useful if the resulting patterns represent meaningful, known synoptic structures. However, this is not guaranteed and care needs to be taken to distinguish between good and poor methods in this sense. Manual schemes, such as Hess-Brezowsky and Lamb, are typically based on valuable synoptic experience, but suffer from potential inhomogeneity when catalogues are created, due to the subjective nature of the classification decisions. Objective methods of classifying synoptic patterns according to these pre-determined types result in homogeneous series and retain an element of the synoptic experience that can be so valuable. Other subjective-manual methods have been documented, which have not been objectivized. Such methods could be very valuable to the COST733 action, because they are often based on a keen knowledge of regional synoptic types derived from many years of local synoptic experience. Nevertheless, such methods can only be evaluated when a daily catalogue of classified types exists in digital form. Unfortunately, this is rarely the case.

There were almost 70 methods reported in the questionnaire returns. An initial analysis was undertaken to remove those methods which were clearly not appropriate for use in COST733. These included methods which were too local in scale or based on local correlations with highly specific quantities, thus being unable to define synoptic-scale types. Other methods were rejected by having too few types (therefore having too little informational value) or being based only on mid-tropospheric variables (therefore yielding types with too little surface structure), or having too many types and sub-types (therefore having too little focus and relevance). Where several WTCs were based on essentially the same generic method (e.g. Jenkinson-Collison), only a single, representative method was selected.

A provisional list of selected methods was disseminated to WG1C experts in April 2006. Several experts then responded with recommendations, based in par-

..... 3.3 Development and history of the COST733CAT database

ticular on applicability in their own region. Several WTC authors were also contacted in cases where availability or detail was unclear in order to clarify whether their methods should be included or not. In particular, a number of promising methods could not be used because no digital catalogue could be provided.

At the end of the WG1C working period 19 WTCs remained in final selection.

3.3.2 Catalogs

In the first round we planned to get the catalogs of the classifications to be calculated by their authors or by somebody who has used the classification earlier. For that reason we standardized the input data and the domains for what the catalogs would be calculated. For the initial data set of classifications the ERA-40 data set at 12 UTC was selected. 12 standard domains were selected for the whole Europe where to test the methods. A map of domains locations is shown in Fig. 3.2, the exact locations in degrees are presented in Tab. 3.1. There is one large domain and 11 sub-domains, representing different geographical regions of Europe. These sub-domains overlap in places. Generally, the numbers of grid-points to be used are numbers which are factors of 2 and 3 only. The domains are approximately square in real spatial dimensions. The sub-domains all use the 1×1 degree data, the large domain should use specific data points every 2 deg lat and every 3 deg long (without interpolation).

3.3.2.1 Version 1.0

First catalogs were loaded to an internal ftp site in summer 2007 (deadline: end of September 2007). The first version 1.0 of COST733CAT was actually ready to release on February the 1st 2008. It included weather/circulation types of 26 different methods. The number of types was as original and also the field that was classified was as in the original version of method respectively. For some of the methods several numbers of types have been used and also SLP, Z500 or both were used for circulation classification. Most of the catalogs were calculated by the authors themselves. The COSTCAT733 v1.0 includes also 5 manual classifications. The list of the respective methods on the COST733CAT-1.0 is presented in Tab. 3.4. These methods are partly named after their authors/calculators, sometimes reflecting the algorithm or input data used, and at this time appear relatively inconsistent.

Table 3.4: The list of methods that are included into COST733CAT-1.0. The methods are mostly named after their authors/calculators. Looking for these names in the reference list, it is possible to find more information about the methods.

<i>No</i>	<i>Abbreviation</i>	<i>Author/calculator</i>
1	CEC	Enke/Spekat, cluster based
2	ESLPC10	Erpicum, SLP 10 types
3	ESLPC30	Erpicum, SLP 30 types
4	EZ500C10	Erpicum, Z500 10 types
5	EZ500C30	Erpicum, Z500 30 types
6	GWT	Beck, GrossWetterTypen, Prototypes
7	LITADVE	Litynski/Pianko, ADVEction
8	LITTC	Litynski/Pianko, Circulation Types
9	LUND	Lund/Philipp, pattern correlation
10	LWT2	James, Objectified Lamb WeatherTypes
11	P27	Kruzinga/Post, PCA based
12	PCACA	Rassila Alvarez, Cluster Analysis of PCs
13	PCAXTRKM	Esteban, S-Mode PCA based
14	PCAXTR	Esteban, S-mode PCA based with one-iteration-kmeans
15	PETISCO	Petisco/Rassilla Alvarez
16	SANDRA	Philipp, Simulated ANnealing clustering
17	SANDRAS	Philipp, Simulated ANnealing clustering of Sequences
18	TPCAV	Huth, T-Mode PCA, various PCs
19	TPCA07	Huth, T-Mode PCA, 7 PCs
20	WLKC733	Dittmann/Krennert, Philipp, WetterLagenKlassifikation
21	HBGWL	Hess, Brezowsky/Gerstengabe, Werner, GrossWetterlagen manual
22	OGWL	James, Objectivized GrossWetterLagen
23	PECZELY	Peczely/Bartholy, manual
24	PERRET	Perret/Duding, manual
25	SCHUEEPP	Schüepp/Schiemann, manual
26	ZAMG	Zentral-Anstalt für Meteorologie und Geodynamik/ Krennert, manual
27	NNW	Neural network self-organizing feature maps

..... 3.3 Development and history of the COST733CAT database

The COSTCAT733 v1.0 output was in the form of ascii-text files, with names e.g. `James_LWT2_D00.txt`, `James_LWT2_D01.txt`, etc., where D00 is the large domain, D01 is the first sub-domain, and so on. Each of these data-files contains a simple list of days and synoptic type numbers, formatted regularly. For example, the LWT2 system has 26 types, numbered 1 to 26. Thus, the output will look like this (example):

```
1957  9 1 14
1957  9 2 26
1957  9 3  2
```

and so on, until..

```
2002  8 30  7
2002  8 31 17
```

There are also a free-format meta-files containing information about the types. e.g. for LWT2 this would be in `James_LWT2_Meta.txt`, where the author of the method has written some details about his/her method. The same simple format of files has been hold for single classifications for a single sub-domain for all later versions of COST733CAT.

In the next version COST733CAT-1.1 (2008/02/17) some errors were corrected and NNW included.

3.3.2.2 Version 1.2 (2008/07/12)

This is the version of the catalog that was mostly used for analysis and evaluation during the period of the COST Action 733. Altogether there are 22 methods, but the actual number of catalogs is larger as the methods are now more standardized. Due to the evaluations done by the WG3 and WG4 one of the most important factors to describe the performance of the classification is the number of types. The higher the number of types the higher is the skill score. What means that there is no sense to compare the results of the classifications that have very different numbers of types. Therefore the suggested numbers of types have been decided to be 9, 18, 27 for next calculations of classifications in order to compare the algorithms and not the configuration of the classification. The other suggestion of standardization was to use SLP as the field that is classified for all methods.

Some changes also include methods:

1. Full year CKMEANSC09, CKMEANSC18 and CKMEANSC27 replaces CEC
2. Kirchofer (KH) added as a new method
3. ERPICUM catalogues replaced with more equal class sizes
4. NNWC09 to NNWC27 catalogues created with (exhaustive) 2000 training epochs
5. HBGWT added as Hess/Brezowsky “Grosswetter Types” with 10 classes

3.3.2.3 Version 2.0

The last version of the data set produced within the COST Action 733 period includes 17 objective methods and 6 subjective ones. However, the actual number of daily catalogs is more than 500, as in addition to catalogs obtained by classifying the whole year, also seasonal classifications are included. There are also classifications of 4-day sequences instead of single day classifications only and in some cases there are several other meteorological parameters that are classified, besides SLP. Also the abbreviations of the names of the methods were standardized because of computational needs. For example the file-name CKM09_YR_S01_SP-Z5-YS-K5_D00.txt gives us information at first about the method CKM – k-means, number of types – 09, that the fields are classified for the whole year – YR, on the daily level – S01, for the large domain D00. The abbreviations of the fields what are for the basis of classification can be found in Tab. 3.5. The new abbreviations of the names of the methods are presented in Tab. 3.6.

Table 3.5: Abbreviations that are used in file names of COST733CAT-2.0.

YR	Full year
SE	Seasonal (i.e. 7 types for Winter (DJF), Spring (MAM), Summer (JJA), Autumn (SON) respectively
S01	Single day classifications
S04	4 day classifications
SP	Mean Sea Level pressure (MSLP)
Z1	1000 hPa geopotential height (GPH)
Z9	925 hPa geopotential height
Z8	850 hPa geopotential height
Z5	500 hPa geopotential height
K5	Thickness between 500 hPa and 850 hPa geopotential height
YS	Vorticity of the MSLP field
Y9	Vorticity of the 925 hPa GPH level
Y5	Vorticity of the 500 hPa GPH level
U7	zonal wind component at the 700 hPa GPH level
V7	meridional wind component at the 700 hPa GPH level

Some of the classifications that are included into this version of COST733CAT are computed by their authors, with “o” in the name of the file, but most of them are computed by COST733CLASS, a special software package which has been developed for this purpose within the framework of COST Action 733.

..... 3.3 Development and history of the COST733CAT database

Table 3.6: Abbreviations that are used in file names of COST733CAT-2.0 for the names of the methods, in PHILIPP et al. (2010) is shown by whom this catalog has been computed.

GWLo	Hess-Brezowsky GrossWetterLagen (HBGWL/HBGWT) [original]
PECo	PECzely [original]
PERo	PERret [original]
SUEo	SchUEepp [original]
ZMGo	ZAMG [original]
GWT	GrossWetterTypes (GWT) [COST733CLASS]
JCT	Jenkinson-Collinson-Types [COST733CLASS]
LWTo	Jenkinson-Collinson “Lamb WeatherTypes 2” (LWT2) [original]
LIT	Litynski (LITADVE/LITTC) [COST733CLASS]
LITo	Litynski (LITADVE/LITTC) [original]
WLK	WetterLagenKlassifikation (WLK) [COST733CLASS]
WLKo	WetterLagenKlassifikation (WLK) [original]
KRZ	Kruizinga (P27) [COST733CLASS]
KRZo	Kruizinga (P27) [original]
PXE	Pca-eXtreme scores reassigned by Euclidean distance (PCAXTR) [COST733CLASS]
PXEo	Pca-eXtreme scores reassigned by Euclidean distance (PCAXTR) [original]
PCT	obliquely rotated PCA of subsamples in T-mode (TPCA) [COST733CLASS]
PCTo	obliquely rotated PCA of subsamples in T-mode (TPCA) [original]
PTT	orthogonally rotated PCA in T-mode [COST733CLASS]
LND	LuND [COST733CLASS]
KIR	KIRchhofer (KRC) [COST733CLASS]
ERP	ERPicum [COST733CLASS]
ERPo	ERPicum [original]
PTSo	PeTiSco [original]
CKM	CKMeans [COST733CLASS]
CKMo	CKMeans [original]
NNWo	Neural NetWork (Kohonen SOM) using 2d-topology [original]
SOM	SelfOrganizing Maps (Kohonen SOM) using 1d-topology [COST733CLASS]
CAP	Cluster Analysis of Principal components (PCACA) [COST733CLASS]
PXK	Pca-eXtreme scores reassigned by K-means (PCAXTRKM) [COST733CLASS]
PXKo	Pca-eXtreme scores reassigned by K-means (PCAXTRKM) [original]
SAN	Simulated ANnealling clustering [COST733CLASS]
RAC	RANdom Centroid classification [COST733CLASS]

3.4 Development and features of the `cost733class` software

3.4.1 Introduction

One of the key tasks assigned to WG2 was the calculation of the time series of weather type data using the selected methods of WG1 in a homogenized manner, described in Section 3.1, that would enable the statistical evaluation, by WG3 (Chapter 4), and testing, by WG4 (Chapter 5), of the various methods.

The work of WG2 started after WG1 completed its work programme in September 2006, and the initial approach was to ask the respective authors to prepare the homogenized classification catalogues and submit them to WG2. Apparently not all the selected classifications had a corresponding author able to provide these catalogues, so these were programmed by WG2. As the work progressed and the standardized method configuration took its final form it became clear that it wouldn't be practical to rely on the original authors to provide the continuously growing number of catalogue variations needed.

The obvious step was to develop a software tool that could generate classification catalogues according to the methods originally selected by WG1, as well as others that were added on the way, according to the standardized method configuration, in a simple and unified manner. In that respect the original authors of the various classification methods have been requested to contribute the software code they were using, or if that was not possible to provide detailed information on the way their method was implemented. The various inputs collected were rewritten and compiled into `COST733CLASS`, a FORTRAN90/95 software package by A. Philipp, F. Streicher and C. Beck, University of Augsburg. The code was made available to the wider public on the `COST733` wiki page and is distributed under the GNU GPL license v3.

The software is constructed in a modular way, in order to facilitate the addition of methods and features. There are modules responsible for input and output data handling, preprocessing, some generic classification/data reduction methods like principal components, k-means and hierarchical clustering, one module for each classification method used in the project, as well as some extra methods. The software is primarily intended for use under Unix/Linux systems but it has been successfully used under Windows as well. Fully functional binaries for less experienced Windows users, are provided by F. Kreienkamp, CEC. The tool is partly parallelized thus it is considerably faster for classifications of large datasets compared to other statistical packages.

The functionality of `COST733CLASS` is controlled by command line arguments, i.e. the user has to type the command into a terminal or console providing a command prompt. The main reason is that the software was intended to be suitable for shell scripts (batch files in Windows environments) and should also run on compute servers in the background. There is no graphical user interface (GUI) at the moment, even though it is possible to develop a simple GUI that produces the command line arguments. The usage of command line arguments that are

automatically recognized by the software and usually followed by other expressions, provides a very flexible environment allowing for a multitude of variations either relevant for the data input and preprocessing, or for the way each individual classification method is implemented.

The COST733CLASS package has been used to produce some of the catalogues found in COST733CAT v1.2 database and for the entire set of COST733CAT v2.0 catalogues, except of course those marked as original versions (see Tab. 3.3).

3.4.2 Timeline of development

As already mentioned, from the start of WG2 work there was a need for some methods to be programmed from scratch since the original authors were not available for generating the catalogues (LND and KIR methods, for abbreviations of methods see Tab. 3.6 on page 57).

The need for WG2 to be able to recalculate the various catalogues on its own was first mentioned in the Augsburg Meeting (07–08/03/2008). There, it was decided that catalogues should be recalculated for fixed numbers of types where possible and for all domains. The issue of publication on/of the collection dataset was also brought up, and it was agreed to ask all contributors for their agreement to publish the catalogues as well as whether program code (preferably FORTRAN90) was available and distributable. Acknowledging the shortcomings of this contributor-based approach the development of a software package that would be able to run classifications varying the primary features was discussed, and netcdf data support was among the desirable features.

In the soon to follow 6th MC/WG Meeting in Ioannina (09–10/05/2008) it was decided that “new method(s)” and the harmonisation of existing methods should be implemented by a free, standardised software-package that, according to the results and recommendations from WG3 and WG4 should be:

- able to run different methods for key pattern definition: thresholds, most frequent, within-type-var, PCA-based
- allow to change easily (by a command line switch):
 - similarity/distance measure
 - number of classes
 - meteorological parameters/levels used (input)?
 - temporal configuration: seasonal, sequences, ...
 - spatial configuration: domain, weighted, etc.

At the time, the release v. 0.12-1 of COST733 classification software package supported only ASCII format data input, and already included the following methods: LND, KIR, SAN, SOM, KMN, PTT (PCA with orthogonal rotation) and a user defined number of classes.

The programming team of WG2 set as a priority to include as many methods as possible under GNU GPL license v3, while at the same ensuring that the original

catalogues were accurately reproduced. Also the idea of a training school on the software tool appeared, upgrading the role of this software package in WG2 list of deliverables.

By the time of the 7th MC/WG Meeting and Midterm Conference in Krakow (22–24/10/2008) the release version was 0.16-03 (already under GNU GPL license since v.14), it was tested in both Unix/Linux and Windows systems and included two more methods (DKM and PXE/PXK). The tool also provided the possibility to calculate sequential classifications, calculate and save the class centroids, and provide custom names for the output files.

The period between the Krakow and the Toulouse WG2 Meeting (26–28/03/2009) was marked by a rapid development of COST733CLASS. The current version 0.19-07 used GNU-“autotools” to simplify compilation and there also was a User Guide bundled with the software. The new methods included were a time constrained version of SAN, HCL (hierarchical clustering), GWT, LIT, WLK, RAN and RAC. Input data could be in the form of multiple ASCII files as well as 6-hourly NCEP/NCAR reanalysis netcdf files. The data preprocessing included weighting between different datasets, and selection of months, hours or dates from a list. Even though SOM, PXE/PXK and PTT were more or less different from the original methods, it was decided that the new catalogues should be calculated using the COST733CLASS software where possible, and that all remaining methods should be included in it.

At the 8th MC/WG Meeting in Larnaca (15–17/10/2009) methods KMN (simple k-means), KRZ, ERP, CAP, JCT, RCC as well as two methods ASS, ASC, for assigning cases to pre-defined centroids, and the evaluation statistic ECV (explained cluster variance) were added to the current version of the software v.0.20-15. Apart from the new methods, there were also options controlling whether raw or normalized data were used in some of the methods, along with more switches tuning key parameters of various methods, e.g. threshold values.

The software was used to generate all catalogues in COST733CAT v.2.0 database, except those provided by the original authors. Till the 9th MC/WG Meeting in Tartu (22–24/03/2010), these catalogues were examined and compared against the original methods and as result some methods have been revised and improved. PCT a t-mode PCA with oblique rotation was the last classification method represented in COST733CAT that was added in the software, leaving just one automated method, PTS, not yet included. Another method KMD, not included in COST733CAT was also added, as well as an option to calculate centroids for a given classification (CNT) some more evaluation statistics: EVPF, WSDCIM, FSIL, SIL, DRAT and CPART a method calculating statistics on the comparison between two or more classifications. These evaluation and comparison statistics comprise the entire set of tools used by WG3. In terms of functionality 3-D visualization was added for SOM, SAN and CKM, yet only available under Unix/Linux, and more options on data handling and tuning of the various methods.

COST733CLASS v 0.23-03 included all the features detailed by WGs 3 and 4 at Ioannina in May, 2008, and more, so there was a question raised regarding the main focus for software development for the remainder of the Action. A questionnaire

..... 3.4 Development and features of the COST733CLASS software

was circulated concerning the end-user aspect of the software, especially possible difficulties in using it as well as possible omissions and strong points. Also, special attention was given to the User Guide since this was thought to be a key point in the future usability of the software.

In order to indicate that the software has reached a state where it is ready for use also for external users the version number has been switched to 1.0 in January 2011. At the same time the program code has been migrated to the SVN versioning system including a TRAC development wiki-site at <http://cost733.geo.uni-augsburg.de/cost733class-1.2> (note that the ...-1.0 address does not work anymore). Beside improvements for data input and preprocessing, additional classification methods (e.g. mixture models) and also procedures for using classifications for downscaling have been added or are under work. The development of the software maintained at the University of Augsburg will keep going on after the official end of COST Action 733.

3.4.3 Usage, features and flexibility of the software

As mentioned above, the user has to type command line arguments into a terminal to make the program do what he/she wants. Command lines can vary from being fairly simple to very complicated, especially with regards to data configurations. Even though this form of program control seems somewhat cumbersome it also allows maximum control and usage of COST733CLASS features.

The various features of this software tool can be grouped under some key categories, namely: input, preprocessing, classification methods, output, and evaluation statistics.

3.4.3.1 Input

The data input interface can read ASCII files with one line per day (object to classify) and one column per variable (parameter defining the objects e.g., grid points), as well as NETCDF files (e.g., NCEP/NCAR-Reanalysis-1). The current version supports netcdf v.4.0.1 files with COARDS conventions (<ftp://ftp.unidata.ucar.edu/pub/netcdf/Conventions/COARDS>) and time units hours since a given date.

It is possible to classify data from more than one file simultaneously. For instance it is possible to classify aggregate objects consisting of (daily) fields of SLP, T2m and GPH500. When using ASCII data, the user may describe the coordinates of the domain and the spatial resolution of the data which are automatically retrieved from the self describing NETCDF format. Further descriptors can be used to select sub-regions with ascii or netcdf data.

Also the dates of the objects can be provided for ASCII files by command line arguments (again this is done automatically for NETCDF files). Also date columns within the files can be used and might be added to the output data if requested. Some methods depend on given time information for others it can be omitted. Again it is possible to select sub-periods with special descriptors. It is possible to

select sub-periods in various ways e.g. specific months or hours, or even days from a user provided list. It is up to the user to ascertain that there are no gaps in the data. Also there is the possibility to use the first n objects (days) for testing, instead of the entire dataset

3.4.3.2 Preprocessing

A very significant feature, for both ASCII and NETDCF data, is the possibility to classify sequences of objects e.g. three day fields instead of single day fields.

When using multiple data files (parameters) it is possible to assign weights to each one of the parameters. Furthermore, since several methods require some of normalization of the the raw data, it is also possible to select whether each dataset will be normalized as a whole and multiplied by the weight assigned to it, or by a weight adjusted for the number of variables in the dataset.

Also, since some methods are very time consuming there is an option to reduce the number of variables through a PCA preprocessing, thus speeding up the process. Of course the motivation may also be to remove collinearity. The number of PCs, which can be rotated obliquely or orthogonal by several variants, may be chosen directly or by the fraction of variance which should be retrieved. The resulting scores may be weighted by the explained variance of the referring PC.

The development version of the software includes several preprocessing features many of which have already been programmed as parts of various classification methods, such as a low pass Gaussian filter (used for instance in CAP), various kinds of anomalies calculation and normalization (most PCA based methods), and a PCA preprocessing option for general use.

3.4.3.3 Implemented methods

The methods implemented in the current version of COST733CLASS-1.0 are:

NON: just read (and write) data and exit

GWT: prototype 'Grosswetterlagen', correlation based, with raw or normalized vorticity coefficients

LIT: Litynski thresholds on a single circulation field

JCT: Jenkinson Collison scheme for Lamb weather types

WLK: threshold based using either raw or anomalies of cyclonicity, and user specified wind sectors and other tuning parameters

PCT: t-mode principal component analysis of 10 subsets, oblique rotation

PTT: t-mode principal component analysis, varimax rotation

PXE: s-mode PCA with user selected threshold for high positive and negative scores to classify objects, and various data normalization options

PXK: using PXE results as seeds for conventional k-means optimization

KRZ: Kruizinga PCA scheme

LND: count most frequent similar patterns with user selectable distance threshold to search for key patterns

KIR: count most frequent similar patterns with user selectable threshold value

..... 3.4 Development and features of the COST733CLASS software

ERP: count most frequent similar patterns, angle distance, adjusting thresholds
HCL: hierarchical cluster analysis according to seven different algorithms
KMN: k-means cluster analysis according to Hartigan/Wong algorithm, and user set number of iterations
CAP: 11day low pass filtered data, s-mode PCA, ward-clustering, k-means
DKM: k-means (simple algorithm) with most different start patterns
CKM: like DKM but eventually skips small clusters <5% population
SAN: Simulated ANnealing and Diversified RAndomisation clustering, with user set number of iterations/runs and cooling rate.
SAT: SANDRA with time constrained clustering (near objects classified together), and user set number of iterations/runs
SOM: Self Organising Maps (Kohonen neural network) with either 1 or 2-dimensional topology, and user set number of iterations/runs
KMD: Partitioning Around Medoids with 4 different distance metrics
MIX: Partitioning with gaussian mixture model.
RAN: just produce random classification catalogues
RAC: determine centroids by random and assign objects to it
RCC: like RAC but with minimum distance between centroids
ASC: no real method: just assign data to given centroids provided by the user, distance metric can be determined by option `-dist`
CNT: calculate centroids of given catalog and data

The possibility to generate catalogues with, at least in principle, any desirable number of classes (currently between 2 and 256) was one of the key features required from the beginning of the development of COST733CLASS. Some methods, are inherently not compatible with this feature. Notably, LIT can only produce 9, 18 and 27 classes, while PXE/PXK need to start with an even number of classes, even though by elimination of empty classes the final outcome might be an odd number of classes. Class numbers in output file are sorted by class size (`cla=1` is the most frequent class) for SAN, SOM, KMN and DKM.

3.4.3.4 Output

It is possible to have the input data written as output (for testing purposes), as well as the preprocessed data actually used by the classification method.

Default catalogue output file names reflect the method and number of classes, but the user is free to choose any output name for the catalogue. For methods producing multiple classifications (one per run) it is possible to have them all in the output file instead of only the best one. Datum columns may be added to the output files with various formats. Other output files can be produced, if selected, such as files containing the centroids/composites of the type means, or the index data (e.g. scores and loadings for PCT) used for classification to file named `<char>.<ext>`

The most basic screen output is the “help” screen that provides a comprehensive overview of the features and switches used in the command line. Screen output during running a method, can be adjusted by the command line from practically

none to providing detailed information about the current run, on the expense of computational speed. For Unix/Linux systems only, there is a 3D-visualisation output for 2-dimensional SOM, SAN and CKM. This feature requires compilation with OpenGL libraries installed. It can also produce single-shot jpg-images as shown in Fig. 3.18 which can be used to create videos.

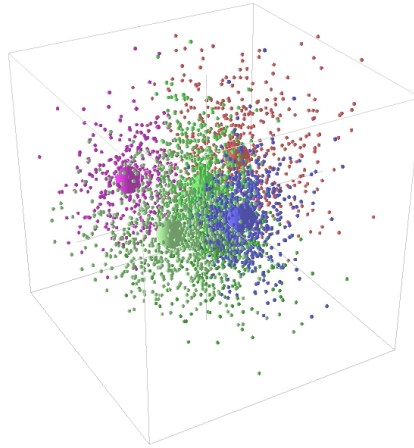


Figure 3.18: COST733CLASS graphics: three-dimensional OpenGL graphic illustrating the classification process of data objects (small spheres, variables projected into three dimensions by PCA) into 5 clusters (centroids denoted by large spheres) using the k-means method.

3.4.3.5 Evaluation statistics

Further to the classification methods, the current version of the software also includes the possibility to calculate most of statistical indices used by WG3 in order to evaluate the quality and performance of the various catalogues:

CPART: calculate comparison indices (RI, ARI, JI, MI, NMI) for all combinations of ≥ 2 given partitions

ARI: calculate only (adjusted) Rand indices for two or more partitions given by `-clain`

ECV: evaluation of classifications by Explained Cluster Variance using either raw or monthly normalized data

EVPF: evaluation in terms of explained variation and pseudo F value

WSDCIM: evaluation in terms of within-type SD and confidence interval

FSIL: evaluation in terms of the Fast Silhouette Index

SIL: evaluation in terms of the Silhouette Index

DRAT: evaluation in terms of the distance ratio within and between classes

The last five indices can be calculated either on raw data, daily or monthly anomalies.

3.4.4 User Guide

As already mentioned a User Guide was first distributed along with the software code in v.0.19 series, around March, 2009 and has been augmented and improved ever since. It provides information on how to download, install and compile the COST733CLASS under Unix/Linux as well as Windows systems. There is a brief introduction in the main features along with some examples of basic command lines, followed by a more detailed description of the various arguments and switches used to control the software.

Special attention is given in the description of the classification methods as these are implemented in COST733CLASS, since there might be differences or the possibility of variants with respect to the original methods.

Finally, abiding to the principles of open source software, there is a section with information on how to add more methods and features in the software. The COST733CLASS User Guide can be found on the software page at <http://cost733.geo.uni-augsburg.de/cost733class-1.2>.

Working Group 3: Evaluation and comparison of classification methods

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4.1 Evaluation and comparison of classifications

4.1.1 Introduction

Started in 2005 the COST Action 733 (Harmonisation and Applications of Weather Types Classifications for European Regions <http://cost733.met.no/>) represents the most advance effort in building a common overall reference framework for weather type classification in Europe. All the classifications entered in the COST Action has been originally developed and tuned according to an optimization of classification itself through selection of a list of characteristics: variables selection, domain selection, number of classes, computational algorithms, etc. The absence of a sort of “*unique and true*” strategy of circulation classification by means of an identified method for reducing information of atmospheric flows forced the Action plan to create a dedicated working group (WG3) to evaluate classifications and provide a comprehensive guidance for new potential users.

The actual aim of WG3 activities is to develop an evaluation archetype both from an objective point of view, by means of comparing and evaluating classifications through a basic framework of data measuring tools, and by means of a climate framework of reference, based on establishing statistical relationships with surface climatological variables.

4.1.1.1 Why evaluation is needed?

Classification of atmospheric circulation in discrete types (circulation types classifications, CTC) or small number of categories allows us to simplify the analysis of the meteorological, climatological or non-climatic environmental variables thanks to their association to the types obtained. In other words, the most significant conditions associated to the types are highlighted, considering them as more or less homogeneous, a picture of reality that makes easier to interpret and analyse it.

As [BARRY and PERRY \(2001\)](#) describe, identification of discrete categories of pressure patterns or circulation types presents several problems:

1. Atmospheric modes are continuous, so that the delimitation of any boundary between classes is extremely difficult. Although patterns may switch abruptly, on other occasions a gradual evolution takes place.
2. Pressure systems can be of variable intensities, and decisions have to be made as to when to include or neglect minor features such as a small weak low or transitory ridge.
3. There may be a seasonal variation in type characteristics. Generally weather systems are of greatest intensity in winter, when equator-pole heat differences are greatest.

Such properties associated to types based on their temporal/spatial scale, number of types and seasonality, have to be evaluated for knowing how “realistic” is our classification. In other words, the use of classifications on climate studies should be preceded by answering some questions about the representativeness and adjustment of the classifications to our research purposes.

Commonly theory of classifications usually defines as good the groupings that show high differences between groups and low differences into groups. Nowadays, this general definition not cover enough, in terms of climate sciences, the requirements of a “good” classification for the variety of existing methods and applications of CTC. This means that is necessary to has more detailed evaluation guidelines with a higher variety of approximations.

As example in this way, in weather forecast verification some authors point out a widely used three-way classification of the reasons of using evaluation methods [JOLLIFFE and STEPHENSON \(2003\)](#):

- *Administrative*: is a need to have some numerical measure of how well forecast are performing. Otherwise, there is no objective way to judge how changes in training, equipment or forecasting models affect the quality of forecasts.
- *Scientific*: a detailed assessment of the strengths and weaknesses of a set of forecasts usually requires more than one or two summary scores. Sometimes

..... 4.1 Evaluation and comparison of classifications

there are unsuspected biases in either the forecasting models, or in the forecasters' interpretations, or both, which only becomes apparent when more sophisticated verification schemes are used. Identification of such biases can lead to research being targeted to improve knowledge of why they occur.

- *Economic*: different users have different interests. Hence, there is the need for different verification schemes tailored to each user.

Applying all these previous concepts and ideas, some questions can be derived for being applied to Circulation Type Classifications:

1. Does our classification groups well enough the variability existing in the circulation data?
2. Does our classification discriminate well enough the variability of the variables we are interested on analyse (temperature, precipitation, occurrence of natural hazards, etc...) using the discrete types obtained with our classification?
3. Does our classification identify well enough all the relevant spatial patterns existing in our study area and for different seasons?

Considering the previous comments as some of the main questions to be solved for deciding a classification method to use and the properties of the catalogue to be obtained (spatial scale, seasons, variable to classify, number of types, etc...), the work of WG3 has been oriented on finding evaluation criteria for at least answering the 3 previous questions, obtaining results via comparison of the different methods proposed by WG2. These comparisons of methods allow us to quantify the performance of individual Circulation Type Classifications and basic methods in order to provide recommendations for the application of CTCs and for the development of new CTCs [BECK and PHILIPP \(2010\)](#).

Summarizing, WG3 has dealt with 3 main strategies for evaluating the CTC methods and provide recommendations:

a) Basic evaluation methods

In general the quality of any classification can be defined as its ability to arrange entities into groups (classes) that feature maximum internal homogeneity and at the same time maximum external dissimilarity. Based on this assumption the objective of this part of the basic evaluation and comparison studies carried through within WG3 is to perform a quantitative evaluation and subsequent comparison of CTCs by means of the estimation of variability within classes and separability between classes using a set of suitable metrics: the explained variation (EV), the Pseudo-F statistic (PF, [CALINSKI and HARABASZ, 1974](#)), the pattern correlation ratio (PCR, [HUTH, 1996](#)), the within-type standard deviation (WSD) (based on the arithmetic mean of the class-specific standard deviations (SDI) proposed by [KALKSTEIN et al. \(1987\)](#), the confidence interval of the mean (CIM), and the faster Silhouette Index (FSIL, [ROUSSEEUV, 1987](#)).

b) Climatological evaluation methods

One of the major applications of circulation classifications has been in synoptic-climatological analyses. Within this frame, a stratification (sorting) by circulation types is used to characterize weather, environmental, and climate conditions at surface. Numerous studies have been published that aim at distinguishing various quantities among circulation types; the quantities include, i.a., surface temperature (e.g., [CASSANO et al., 2006](#); [USTRNUL, 2006](#)) and its vertical profile ([PEPIN and LOSLEBEN, 2002](#)), precipitation (e.g., [TRIGO and DACAMARA, 2000](#); [GOODESS and JONES, 2002](#); [SCHÄDLER and SASSE, 2006](#)) and its diurnal cycle ([TWARDOSZ, 2007](#)), drought ([VICENTE-SERRANO and LÓPEZ-MORENO, 2006](#)), sunshine duration and wind speed ([KIDSON, 1994](#)), concentrations of atmospheric pollutants (e.g., [FERNAU and SAMSON, 1990](#); [MCGREGOR and BAMZELIS, 1995](#); [JIANG et al., 2005](#); [MAKRA et al., 2006](#)), intensity of urban heat island ([YAGÜE et al., 1991](#); [UNGER, 1996](#)), occurrence of wind storms ([LECKEBUSCH et al., 2008](#)), lower tropospheric thickness ([BARTZOKAS and METAXAS, 1996](#)), snowfall ([ESTEBAN et al., 2005](#)), and surface ice melt ([MOTE, 1998](#)).

The ability to describe distributions of surface weather, climate, and environmental variables is one of favourable properties of circulation classifications. Various techniques have been employed to quantify this ability: correlations between seasonal frequencies of types and seasonal mean climate variables ([ANAGNOSTOPOULOU et al., 2008](#)), tests of equality of mean values ([KOSTOPOULOU and JONES, 2007](#)), methods testing the simultaneous equality of all distributions conditioned by the types, such as the analysis of variance (ANOVA; e.g., [MCGREGOR and BAMZELIS, 1995](#); [MOTE, 1998](#); [JIANG et al., 2005](#)) and Kruskal-Wallis test ([FERNAU and SAMSON, 1990](#)), and tests of homogeneity of two distribution functions, in this implementation testing the equality of a distribution under every single type against the rest of data, including the χ^2 test ([MAKRA et al., 2006](#)) and Mann-Whitney test ([FERNAU and SAMSON, 1990](#)).

In the framework of the WG3 studies, several techniques has been applied: Kolmogorov-Smirnov test, the Brier Skill Score and Spearman's rank correlation coefficient. See [WILKS \(2006\)](#) for more details.

c) Subjective evaluation methods

The basic idea of the method is to evaluate the circulation type classifications from the climatologist background perspective, i.e., highlight the coincidences and differences between the patterns obtained in the catalogues and the spatial patterns that the subjective expert knowledge consider as the main and necessary types to be identified and discriminated in a classification and domain. Relevant circulation types (CT) in terms of, for example, frequency or meteorological behaviour “naturally” exist for the different domains, and considering their characteristics, it exist the possibility of not being well represented by classifications mainly because of methodological limitations. A basic questionnaire was provided to several WG3 participants and results for different domains were obtained.

Strategies **a)** and **b)** have been applied to the different versions of the COST733 catalogues obtained by WG2, feedback that permitted outputs to be considered in the next version calculated. That means that in this report are mainly shown the evaluation results concerning the last output of WG2, the version 2.0 (summer 2010). As exception, evaluation results following the subjective evaluation criteria where obtained only until version 1.2. Reasons for that are related to the impossibility of dealing with this approximation with the amount of data generated at the version 2.0 and the limitations of the method detected when the 1.2 results were obtained.

4.2 Basic evaluations and comparisons of circulation type classifications

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4.2.1 Objectives

In general the quality of any classification can be defined as its ability to arrange entities into groups (classes) that feature maximum internal homogeneity and at the same time maximum external dissimilarity. Based on this assumption the objective of this part of the basic evaluation and comparison studies carried through within WG3 is to perform a quantitative evaluation and subsequent comparison of CTCs by means of the estimation of variability within classes and separability between classes using a set of suitable metrics.

CTCs are applied in a wide variety of synoptic climatological studies with the goal to establish relationships between the large scale atmospheric circulation and environmental variables. In consideration of this fact the evaluation studies performed within the framework of WG3 of COST733 are not restricted to the variable used for classification (mostly baric fields from different atmospheric levels) but comprise as well associated climatic target variables (e.g. temperature, precipitation). Thus the evaluation studies presented herein are highly relevant with respect to the assessment and the understanding of climatic within-type variability as one of the main research topics of synoptic climatology (e.g., [YARNAL, 1993](#); [BRINKMANN, 1999](#); [BECK et al., 2007](#)).

Keeping in mind that one of the main tasks of the evaluation and comparison studies within COST733 is to provide recommendations for the application and the development of classification methods it is of particular importance not only to determine the properties of individual classifications but to identify particular strengths and weaknesses of general methodological classification concepts. In addition to the analyses of differences in performance that can be attributed to specific properties of the varying classification methods it is investigated in how far variations of the basic classification parameters (varying number of types, varying size of the spatial domain, sequential classifications or classifications based on single day fields, seasonal or annual determination of types, only MSLP or multiple input variables) systematically affect the performance characteristics of CTCs.

Finally this part of the COST733 action aspires not only to generate results derived on the basis of selected data samples but moreover to develop and provide applicable tools for performing evaluation and comparison studies of variable classifications on the basis of different datasets to the scientific community. Thus the approaches towards comparison and evaluation of circulation type classifications presented hereafter are included into the publicly available COST733CLASS software that is described in detail in Section 3.3 of this report.

4.2.2 Data and Methods

During the project duration of the COST733 Action the evaluation and comparison studies presented in this chapter have been applied to varying sets of daily circulation type classifications that have been compiled or produced within the framework of COST733. All circulation type data cover the period from September 1957 to August 2002 and are provided for 12 spatial domains (domain 0 to domain 11) of varying size and position embedded into the North Atlantic European region (see Fig. 4.1). Unless otherwise noted results presented in this part of the report refer to analyses that have been performed on the basis of the most recent and most comprehensive version 2.0 of the COST733CAT-database which is described in detail in Section 3.4 of this report.

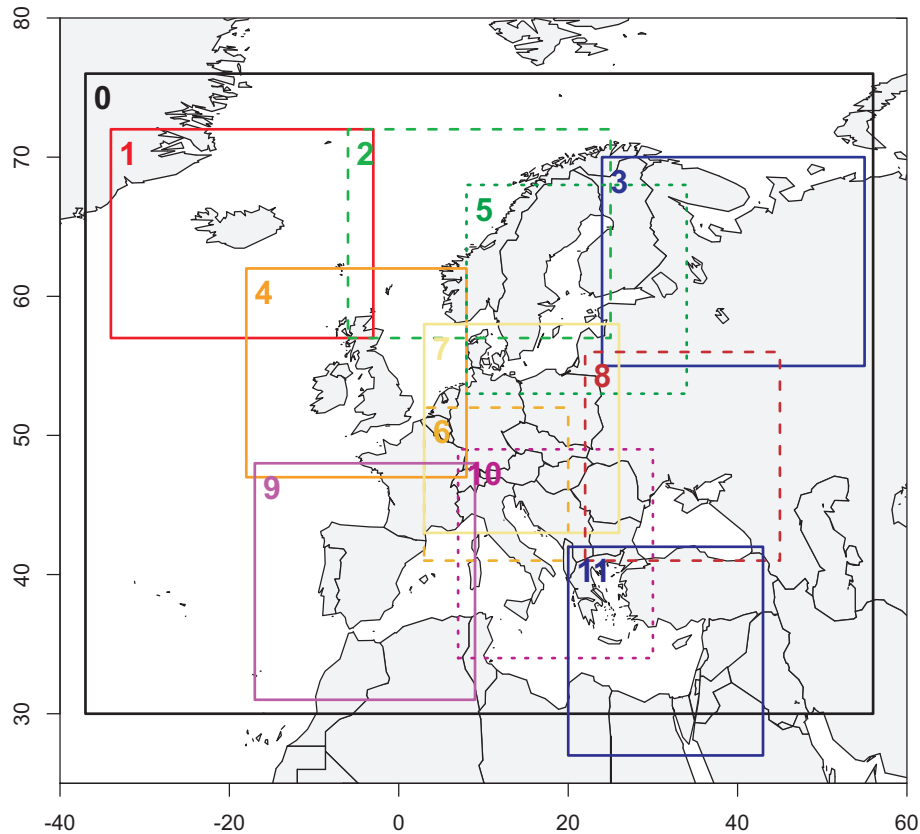


Figure 4.1: Location and extension of the 12 spatial domains (numbers 0–11) for which circulation type classifications are available from the COST733CAT-database.

Data sets used for evaluation purposes are gridded daily 12 UTC data for mean sea level pressure (MSLP), 2 metre temperature (2mT), convective precipitation (CP) and stratiform (large scale) precipitation (LSP) that have been extracted from the ERA-40 reanalysis data set (UPPALA et al., 2005) covering the period from September 1957 to August 2002. Precipitation sums (PREC) have been calculated from CP and LSP. The reanalysis data are used with spatial resolutions of 2° (latitudinal) by 3° (longitudinal) for the large domain 0 and 1° by 1° for the smaller sub-domains 1 to 11. Despite some deficiencies concerning mainly

precipitation data on varying spatial and temporal scales (e.g., BOSILOVICH et al., 2008; OMSTEDT et al., 2005; UPPALA et al., 2005) the reanalysis data provide reasonable estimates for temperature and precipitation in different parts of the North Atlantic European region (e.g. MARTIN, 2004; CROCHET, 2007). Moreover with respect to the analyses presented in this contribution using ERA-40 data has the advantage that all analysis for all spatial domains and all variables can be performed on the basis of only one consistent data set.

A first comparative analysis of the CTCs from the COST733CAT-database determines the similarity between two classifications (or in general the diversity between two partitions of one set of observations) in terms of concurrent assignment of daily atmospheric fields to circulation types. Commonly used indices for quantifying the similarity between two partitions on the basis of the respective contingency matrix are the Rand index (RI, RAND, 1971), the adjusted Rand index (ARI, HUBERT and ARABIE, 1985), the Jaccard index (JI, SOUTHWOOD, 1978), the mutual information (MI, MILLIGAN and COOPER, 1986) and the normalized mutual information (NMI, STREHL and GOSH, 2002).

All five similarity indices have been calculated for all CTCs that are included in the most recent version 2.0 of the COST733CAT-database. However only selected results for ARI are presented in this report, as all similarity indices mentioned above provide comparable results.

In order to assess the performance of CTCs the separability among circulation types and the within-type variability of types are determined by means of several statistical metrics on the basis of daily gridded ERA-40 reanalysis data for the variables used for classification (exclusively MSLP in most cases) and as well for a set of associated surface climate variables

- 2mT – 2 metre temperature
- CP – convective precipitation
- LSP – stratiform precipitation
- PREC – precipitation total (CP + LSP)

In order to prevent the influence of pronounced seasonal frequency variations of circulation types on evaluation results all data (circulation and surface climate variables) have been rescaled to daily anomalies (daily value minus the long-term daily mean) before the calculation of evaluation metrics.

The different metrics that have been calculated for determining separability and within-type variability of CTCs are commonly used as well for estimating the most appropriate number of types when performing computer assisted classifications (e.g., MILLIGAN and COOPER, 1985). The main difference between these two applications is that for finding the adequate number of classes varying partitions resulting from one single method are analysed whereas individual partitions provided by varying methods are analysed within the framework of evaluation and comparison studies performed in WG3 of the COST733 Action.

..... 4.2 Basic evaluations and comparisons of circulation type classifications

In detail the following metrics for determining separability and within-type variability of CTCs have been calculated:

- (1) The explained variation EV is determined as the ratio of the sum of squares within classes (circulation types) WSS and the total sum of squares TSS ,

$$EV = 1 - \frac{WSS}{TSS}. \quad (4.1)$$

- (2) The so called Pseudo-F statistic PF according to [CALINSKI and HARABASZ \(1974\)](#) is defined as the ratio of the sum of squares between classes BSS and the sum of squares within classes WSS additionally taking into account the number of cases n and classes k .

$$PF = 1 - \frac{BSS/(k-1)}{WSS/(n-k)}. \quad (4.2)$$

- (3) [HUTH \(1996\)](#) proposed the pattern correlation ratio PCR as a measure for the separability among circulation types. Here we generalize this metric to the distance ratio $DRATIO$ defined as the ratio of the mean similarity between days (daily gridded fields) assigned to the same circulation type DI and the mean similarity between days assigned to different circulation types DO . Thereby the similarity between objects may be expressed in terms of the Pearson correlation coefficient or in terms of the euclidean distance (or any other distance metric).

$$DRATIO = \frac{DI}{DO}. \quad (4.3)$$

- (4) [KALKSTEIN et al. \(1987\)](#) proposed the arithmetic mean of the class-specific standard deviations SDI to determine the within-type standard deviation WSD for the comparison of synoptic climatological classifications. To account for differing sizes n of classes k , WSD is calculated as the pooled standard deviation.

$$WSD = \sqrt{\frac{\sum_{k=1}^K (n_k - 1) \cdot SDI_k^2}{\sum_{k=1}^K (n_k - 1)}} \quad (4.4)$$

- (5) The confidence interval of the mean CIM gives an indication of the range of uncertainty of a variable's mean values associated to a classification. It has been calculated as the weighted mean (utilizing class sizes as weights) of the type specific confidence intervals of the mean for $\alpha = 0.05$ (the choice of α is arbitrary for comparison purposes).

$$CIM = \frac{\sum_{k=1}^K z_{1-\alpha/2} \cdot \frac{SDI}{\sqrt{n_k}} \cdot n_k}{\sum_{k=1}^K n_k}. \quad (4.5)$$

- (6) [ROUSSEEUW \(1987\)](#) proposed the calculation of the so called Silhouette index *SIL* for evaluating the quality of cluster separation. As the calculation of the Silhouette index according to [ROUSSEEUW \(1987\)](#) is very CPU-intensive when applied to large data sets a modified approach has been used for estimating a “faster Silhouette Index” *FSIL* for use within the COST733 Action. Deviating from *SIL* for any case (day, i) the distances to its own class (fa_i) and its nearest neighbouring class (fb_i) are estimated as the euclidean distances to the respective class centroids for *FSIL*.

$$FSIL = \frac{1}{n} \sum_{i=1}^n \frac{fb_i - fa_i}{\max(fb_i, fa_i)} \quad (4.6)$$

The close relationship between *FSIL* and *SIL* values has been proven by several test runs performed in COST733. Results of the evaluation and comparison of a former version (1.2) of the COST733CAT-database based on the estimation of the above listed evaluation metrics have been recently presented in [BECK and PHILIPP \(2010\)](#).

For this final report the six evaluation metrics listed above have been calculated for all 423 CTCs included in the most recent version 2.0 of the COST733CAT-database (see Section 3.3 for a detailed description), for each of the five ERA-40 surface climate variables (MSLP, 2mT, CP, LSP, PREC), for each of the 12 spatial domains, for 12 individual months, for four 3-month seasons (DJF, MAM, JJA, SON) and the whole year. The resulting 6120 index samples, each consisting of 423 index values provide the basis for subsequent comparative analyses. Standardization of the index values applied to varying subsets has been performed in order to allow for the comparison and the unbiased combination of index values determined for different samples. In order to ensure comparability among the different evaluation metrics the sign of the standardized index values has been changed if necessary in order to attain maximum positive values for those CTCs with minimal within-type variability and maximum separability among types respectively.

Beside the calculation of the evaluation metrics by integrating over the whole set of evaluation variables (or all grid points in the case of gridded evaluation data) evaluation metrics have also been estimated for individual grid points in order to derive information on spatial variations of evaluation indices within the analysed domains. However the estimation of values for specific locations is possible (or reasonable) only for some of the evaluation metrics (EV, PF, WSD, CIM).

In addition to the performance assessment for individual CTCs it is intended to provide an estimate of the performance properties that can be attributed to basic methodological classification concepts. Such a characterization of superordinate groups of basic approaches in terms of objective evaluation metrics is attained by averaging the evaluation metrics over the individual members of the five groups of basic classification approaches [subjective, threshold based (THRES), principal component analysis (PCA), leader algorithms (LEAD), optimization algorithms (OPT)] that are introduced and discussed in more detail in Section 3.2 of this report.

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Moreover the relevance of general settings of the classifications is evaluated. In detail these settings are varying sequence lengths, varying types and numbers of input variables and varying temporal subsets that are used for classification (see Section 3.3 for a detailed description of the different classification variants).

In order to provide plain summaries of the main results of the evaluation and comparison studies performance indices of individual CTCs and superordinate groups of basic methods are estimated by averaging evaluation indices calculated separately for each index sample over varying combinations of samples according to spatial domain, seasonal subset, climatic target variable, variables used for classification, sequence length, temporal resolution or evaluation metric.

All analyses presented in this report have been performed for the whole period of available data from 1957 to 2002. However, in order to check the results for robustness in time selected analyses on the basis of an earlier version of the COST733CAT-database have been performed as well for three shorter subperiods (1957–1977, 1970–1990, 1982–2002, see BECK and PHILIPP, 2010).

As can be deduced from the definition of evaluation metrics given above the different metrics are not independent from each other. Figs. 4.2a–4.2c show scatterplots between standardized performance indices derived by applying the six evaluation metrics to the target variables MSLP (a), 2mT (b) and PREC (c). For all three target variables most distinct similarities can be stated between *EV*, *PF* and *WSD*. For MSLP marked correlations with *EV*, *PF* and *WSD* can furthermore be seen for *FSIL* and – less pronounced – for *CIM*, whereas *DRATIO* (pattern correlation ration in this case) exhibits lowest correlations to all other evaluation metrics. Concerning target variables 2mT and PREC on the contrary *DRATIO* exhibits highest correlations to *EV*, *PF* and *WSD* whereas the remaining metrics (*FSIL*, *CIM*) show much weaker relationships to all other evaluation indices (especially for 2mT).

In this report the focus is put on the results of evaluations and comparisons based on the explained variation *EV* as this evaluation metric is representative for a group of often used metrics (*PF*, *WSD*) for describing classification performance in terms of separability or within-type variability respectively.

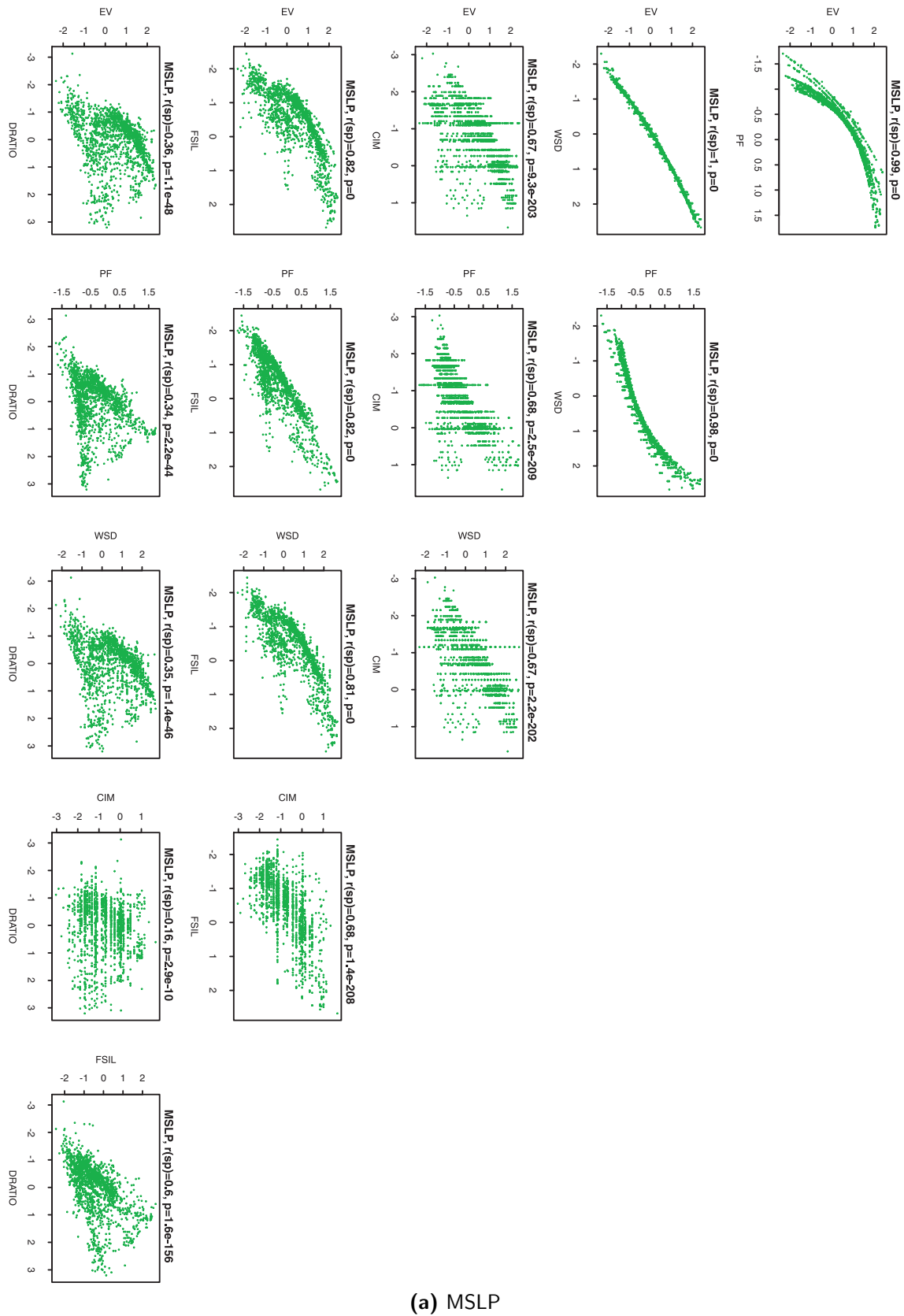


Figure 4.2a: Scatterplots between standardized performance indices derived by applying the six evaluation metrics (EV, PF, WSD, PCR, CIM, FSIL) to the target variable MSLP.

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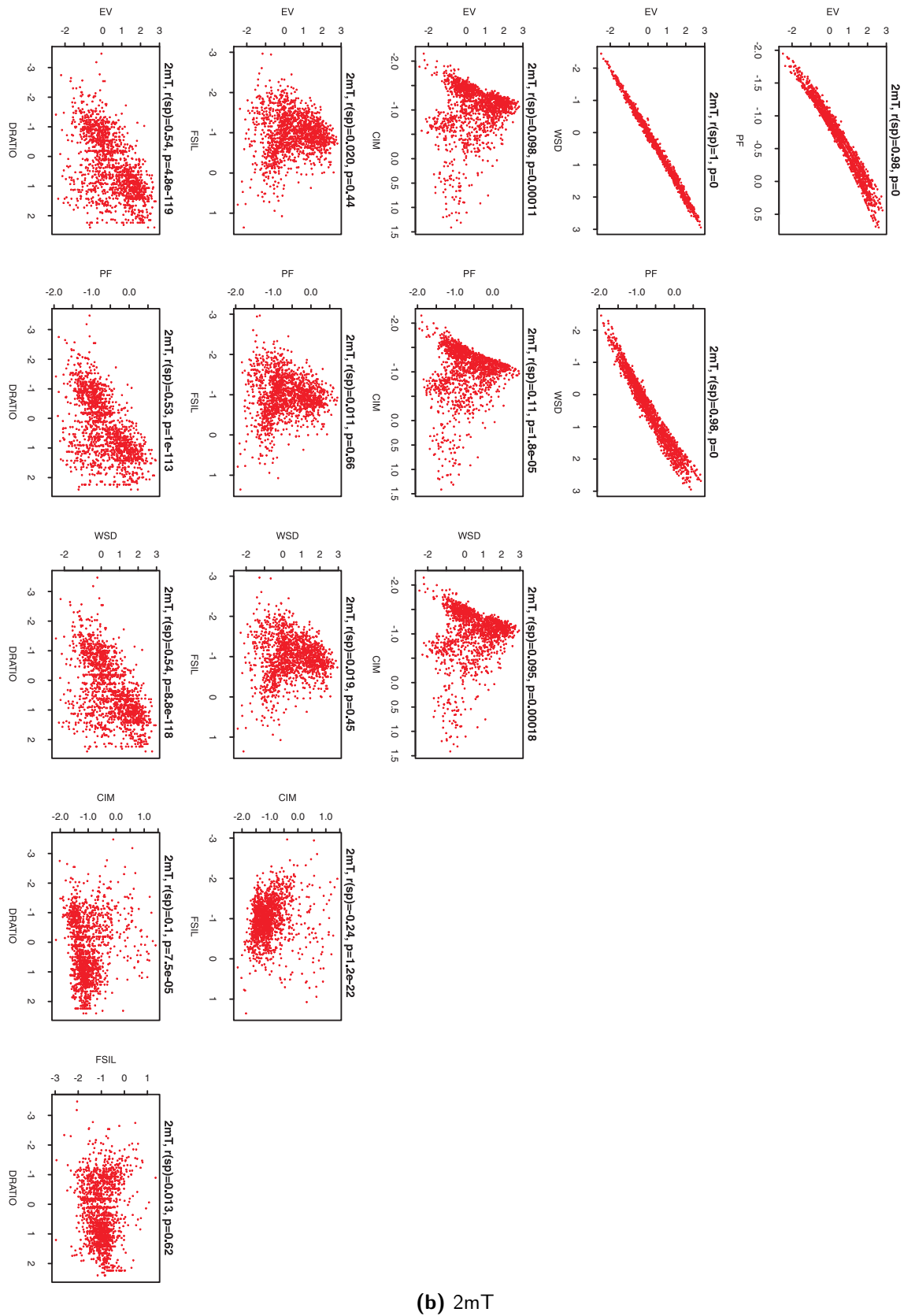


Figure 4.2b: Scatterplots between standardized performance indices derived by applying the six evaluation metrics (EV, PF, WSD, PCR, CIM, FSIL) to the target variable 2mT.

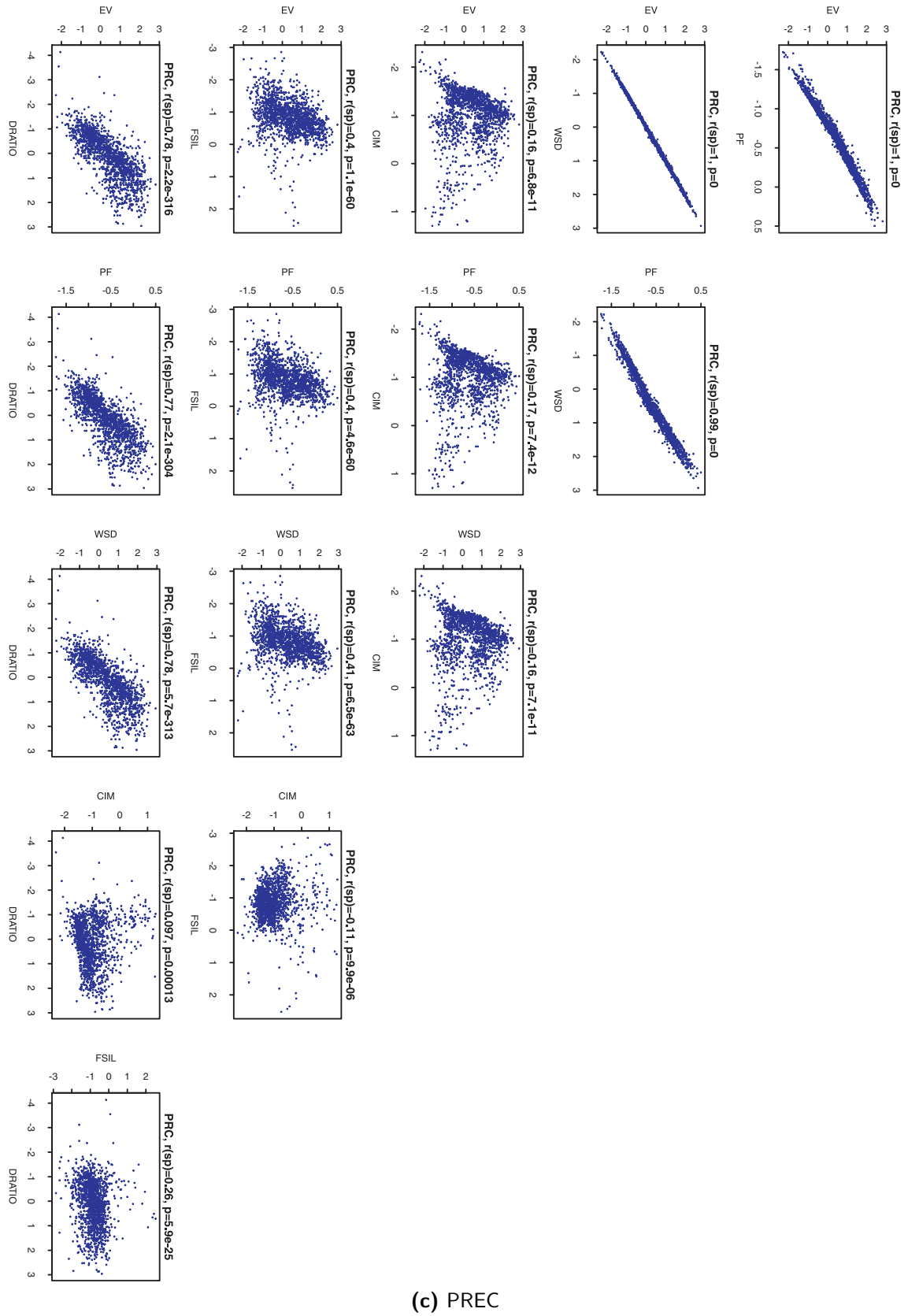


Figure 4.2c: Scatterplots between standardized performance indices derived by applying the six evaluation metrics (EV, PF, WSD, PCR, CIM, FSIL) to the target variable PREC.

4.2.3 Results

In the following results of the application of the comparison and evaluation criteria explained above to the data sets described in Section 4.2.2 are presented.

4.2.3.1 Similarities between circulation type classifications

Fig. 4.3 illustrates the degree of similarity between CTCs in terms of the Adjusted Rand Index *ARI* for CTCs from the COST733CAT database with (a) 9, (b) 18 and (c) 27 types.

The most remarkable findings from Fig. 4.3 are that there are only very few noteworthy high *ARI* values indicating a high degree of similarity between classifications. Apart from *ARI* values near 1 that appear for some “original” classifications and the respective “replications” provided by the COST733 classification software (e.g. LITo and LIT) highest *ARI* values are realized among CTCs from the OPT method group. However as overall result it can be stated that there is no clear tendency towards distinctly higher degrees of similarity within specific method groups than between method groups and – referring to Fig. 4.4 – the similarities between CTCs are even lower in summer than in winter.

This seasonal difference can be seen as well in Fig. 4.5 showing *ARI* indices between different variants of the SANDRA classification. However the main additional information we can get from Fig. 4.5 is that modifications of the classification method have only partly effect on the similarities among the resulting partitions. Whereas for example the classification of 1 day- or 4-day sequences leads to distinct similarity/dissimilarity structures, modifications concerning the number of input variables or the number of circulation types are not characterized through a extraordinary high degree of similarity among the respectively resulting partitions.

4.2.3.2 CTC performance depending on the number of circulation types

When comparing evaluation results of different CTCs it should be kept in mind that evaluation criteria are not only depending on methodological characteristics or external settings of the CTCs but as well on the number of circulation types. This fact is illustrated in Fig. 4.6 showing boxplots of standardized values of evaluation indices integrated over all variables, all spatial domains and seasonal subsets grouped according to the number of circulation types. It is obvious that all evaluation metrics feature distinct dependency on the number of circulation types. Whereas values of *EV*, *WSD* and less pronounced *PCR* increase with higher numbers of circulation types *PF*, *FSIL* and *CIM* exhibit relationships of the opposite sign. Hence the comparison of evaluation results for classifications with distinctly differing numbers of circulation types is strongly biased by the impact of the number of types. Thus – in order to highlight the effects of different classification approaches – evaluation and comparison results are mainly presented for subsets of CTCs having – more or less – similar numbers of circulation types.

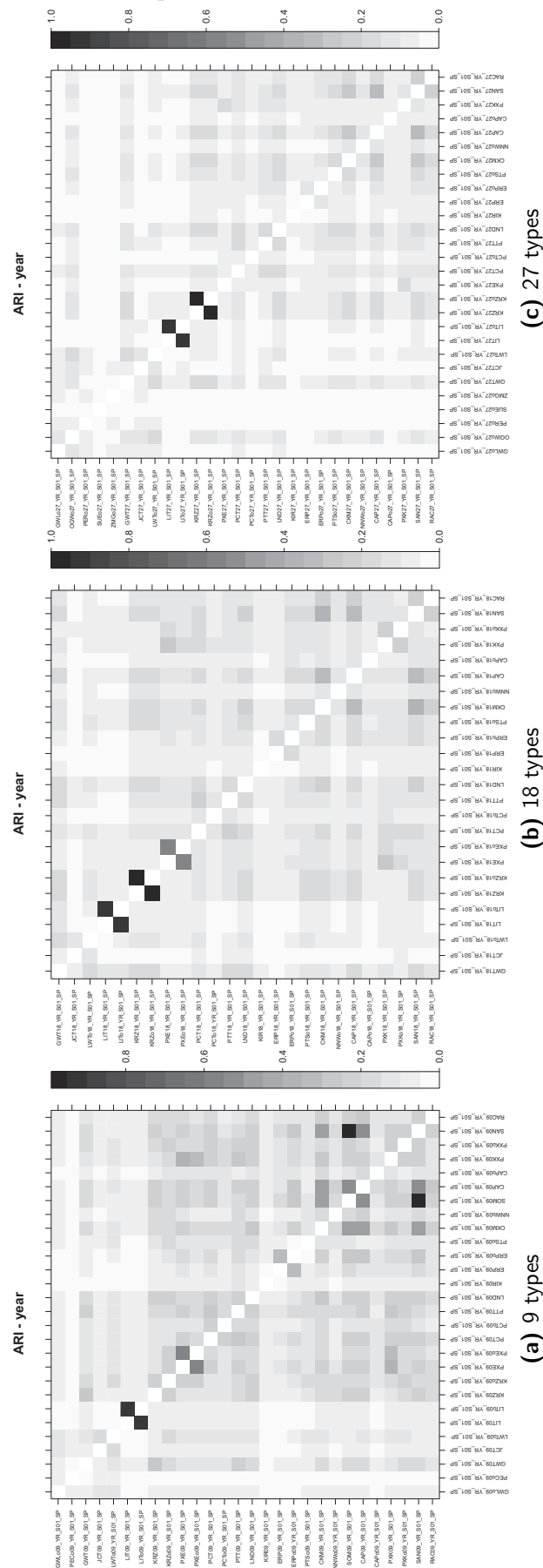


Figure 4.3: Adjusted Rand Index (ARI) between all combinations of circulation type classifications for spatial domain 0 with (a) 9, (b) 18, (c) 27 types (within a range of ± 3 respectively), estimated for the whole year.

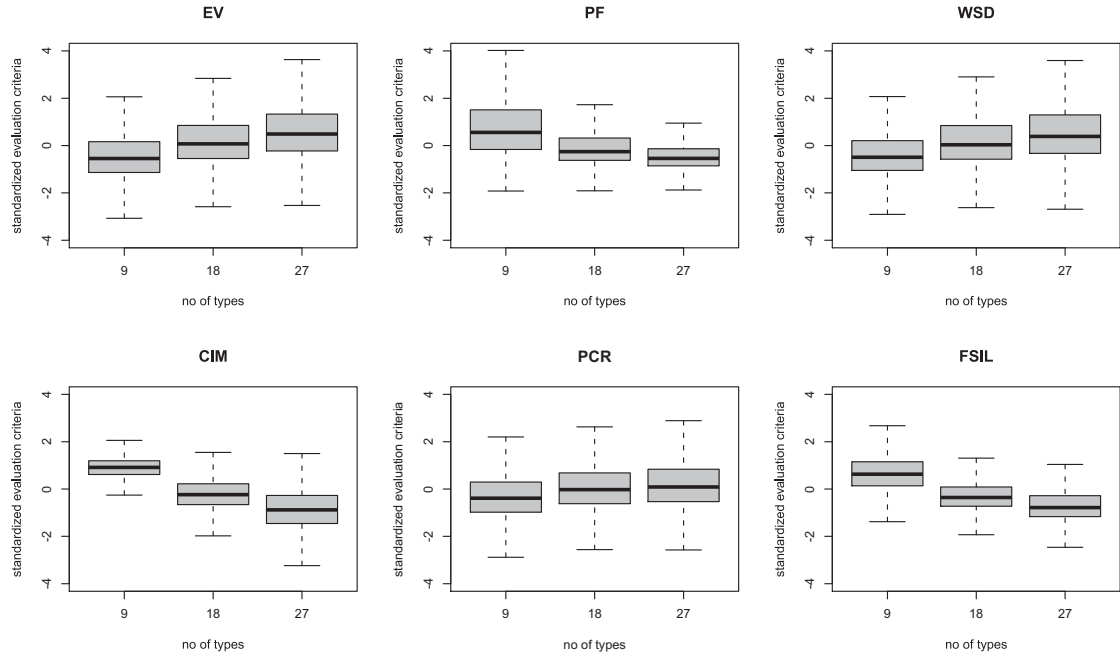


Figure 4.6: Boxplots of standardized evaluation metrics (EV, PF, WSD, PCR, FSIL, CIM, see text for explanation) for circulation type classifications grouped according to the number of circulation types (within the range of \pm the numbers indicated at the x-axis). Boxplots include respective samples of evaluation indices estimated for 12 spatial domains, 17 seasonal subsets and 3 variables for the period 1957–2002. Upper/lower whiskers indicate the 1.5 interquartile range (IQR) from the upper/lower quartile.

ing to the season, the spatial domain and the analysed target variable. Fig. 4.7 illustrates evaluation results in terms of EV depending on the month of the year, the spatial domain and the target variable.

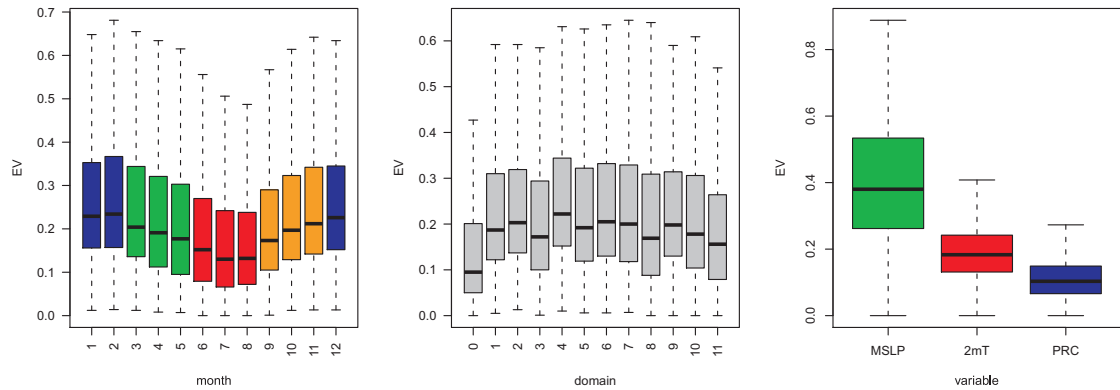


Figure 4.7: Boxplots of EV (determined for the period 1957–2002) estimated for all circulation type classifications from the COST733CAT-database, grouped according to (left) months, (center) spatial domains, (right) evaluated variables. Upper/lower whiskers indicate the 1.5 interquartile range (IQR) from the upper/lower quartile.

Overall best performance can be stated for winter, distinctly lower values of *EV* appear during summer and intermediate *EV* values during the transition seasons spring and autumn. BECK and PHILIPP (2010) identify three clearly separated

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groups of months on the basis of pairwise M-W tests: November to February; May to August and March, April, September, October. [BECK and PHILIPP \(2010\)](#) relate these grouping of months to seasonal variations in the intensity of the coupling between large-scale circulation and climate (most distinct during winter) and the pronounced importance of local-scale processes during the summer half-year not captured by CTCs.

With respect to differences between spatial domains *EV* exhibits considerably lower values for the large North Atlantic-European domain 0 compared to the smaller subdomains (domains 1 to 11). However *EV* differences can be stated between subdomains as well. The more westerly and maritime domains (Iceland, W Scandinavia, British Isles, Baltic, W Mediterranean) are characterized by higher *EV* values whereas the eastern and more continental domains (Central Europe, NE Europe, E and SE Europe, E Mediterranean) exhibit lower values due to a stronger influence of orography and land surface characteristics. Focusing on two domains with comparable location but different size (Central European domain 7 and Alpine domain 6) higher *EV* values can be detected for the smaller domain. Based on a precursor data set ([BECK and PHILIPP, 2010](#)) prove the statistical significance of the above mentioned delineation of spatial domains.

Not surprisingly the best overall performance is reached for MSLP, the variable that is mainly used for classification. For the associated surface climate variables 2mT and PREC *EV* values are considerably lower with PREC featuring minimum values.

[BECK and PHILIPP \(2010\)](#) show that the above mentioned general characteristics of CTCs concerning the dependency of *EV* on season, spatial domain and target variable do not only show up when analysing the whole ERA 40 period from 1957 to 2002 but as well when focusing on shorter subperiods (1957–1977, 1970–1990 and 1982–2002) pointing to the temporal robustness of the described characteristics.

4.2.3.4 Relationships between CTC performance for MSLP and climatic target variables 2mT and PREC

Although the performance of CTCs is analysed separately for the three variables MSLP, 2mT and PREC it is of interest in how far evaluation results for these three variables are interrelated and especially to what extent performance for MSLP may be an indicator for 2mT and PREC performance. Fig. 4.8 shows scatterplots for MSLP and 2mT and MSLP and PREC based on *EV* values of all CTCs with 18 types for all spatial domains and all seasonal subsets. A clear positive relationship between performance for MSLP and the two surface climate variables 2mT and PREC can be seen with higher correlations between MSLP and PREC. However these relationships feature distinct variations among spatial domains and between seasons, as can be deduced from Figs. 4.9 and 4.10, showing seasonal scatterplots for two arbitrarily selected domains. In general (see also [BECK and PHILIPP, 2010](#)) the relationship between performance for MSLP and 2mT/PREC is more pronounced for the large North-Atlantic European domain and during

winter (reflecting seasonal variations in importance of large-scale and small-scale processes for surface climate characteristics).

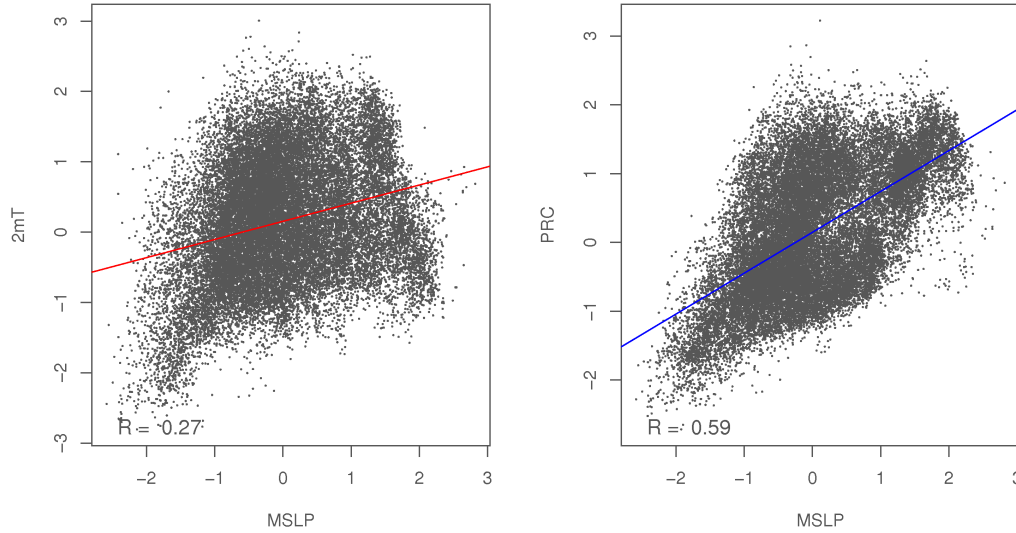


Figure 4.8: Scatterplots illustrating relationships between performance (in terms of EV) of circulation type classifications for (left) MSLP and 2mT and (right) MSLP and PRC, determined for the period 1957–2002 on the basis of all CTCs with 18 types (within a range of ± 3). Estimated over all domains and all seasons. Pearson correlation coefficient is indicated in the lower left of each scatterplot.

4.2.3.5 CTC performance depending on basic method groups

CTC performance in terms of EV grouped according to the five basic method groups (SUB), based (THRES), principal component analysis (PCA), leader algorithms (LEAD) and optimization algorithms (OPT) is illustrated in Figs. 4.11 to 4.14b. Additionally to the mentioned method groups the pseudo random or Random Centroid Methods (RAC, see Chapter 3 for details) are included in the comparisons as well.

CTC performance in terms of EV grouped according to the five basic method groups subjective (SUB), threshold based (THRES), principal component analysis (PCA), leader algorithms (LEAD) and optimization algorithms (OPT) is illustrated in Fig. CB.11 to CB.14. Additionally to the mentioned method groups the pseudo random or Random Centroid Methods (RAC, see Chapter 3 for details) are included in the comparisons as well.

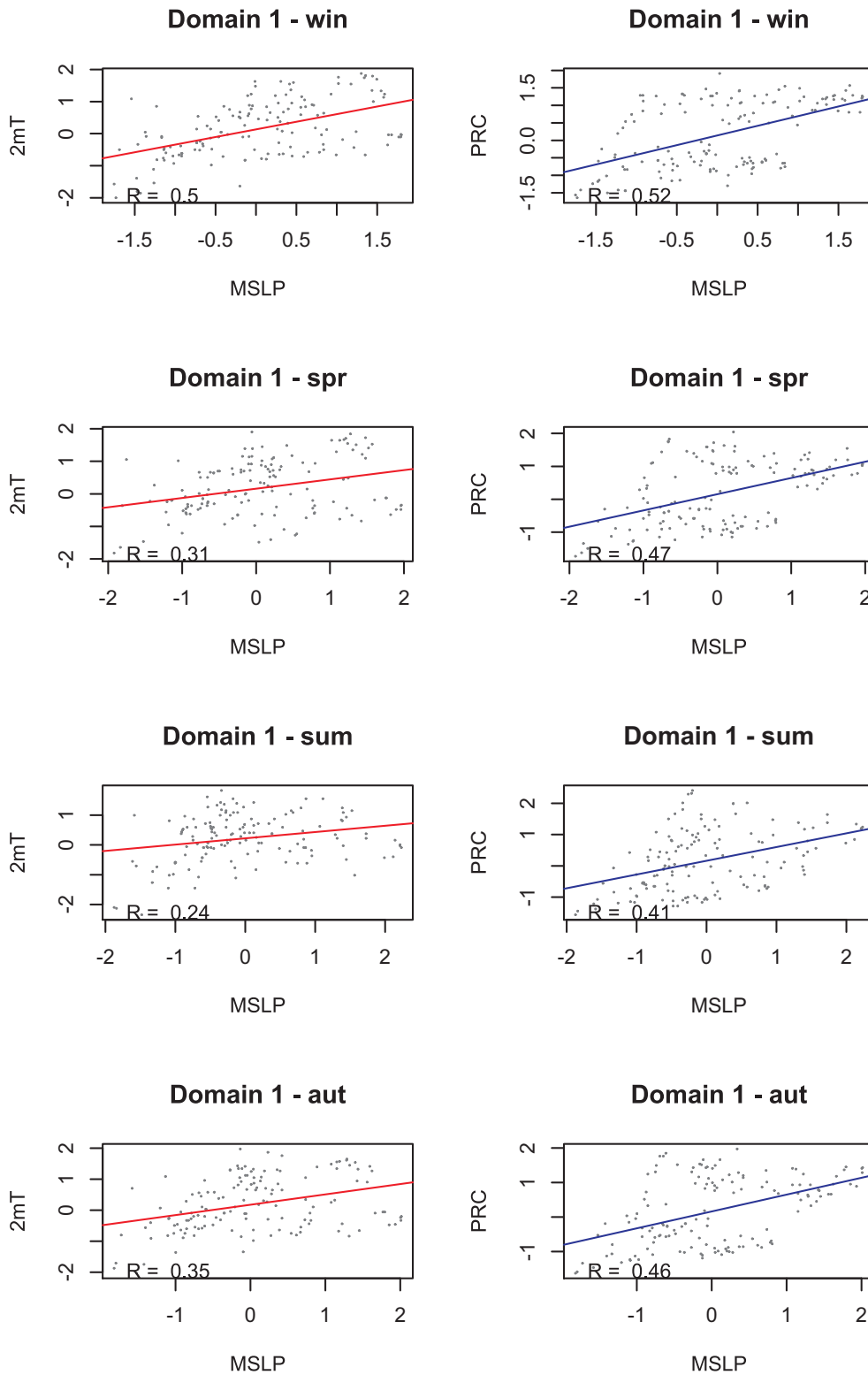


Figure 4.9: Scatterplots illustrating relationships between performance (in terms of EV) of circulation type classifications for (left column) MSLP and 2mT and (right column) MSLP and PRC, for the period 1957–2002 on the basis of all CTCs with 18 types (within a range of ± 3). Estimated for domain 1 for the 3-month seasons winter, spring, summer and autumn. Pearson correlation coefficient is indicated in the lower left of each scatterplot.

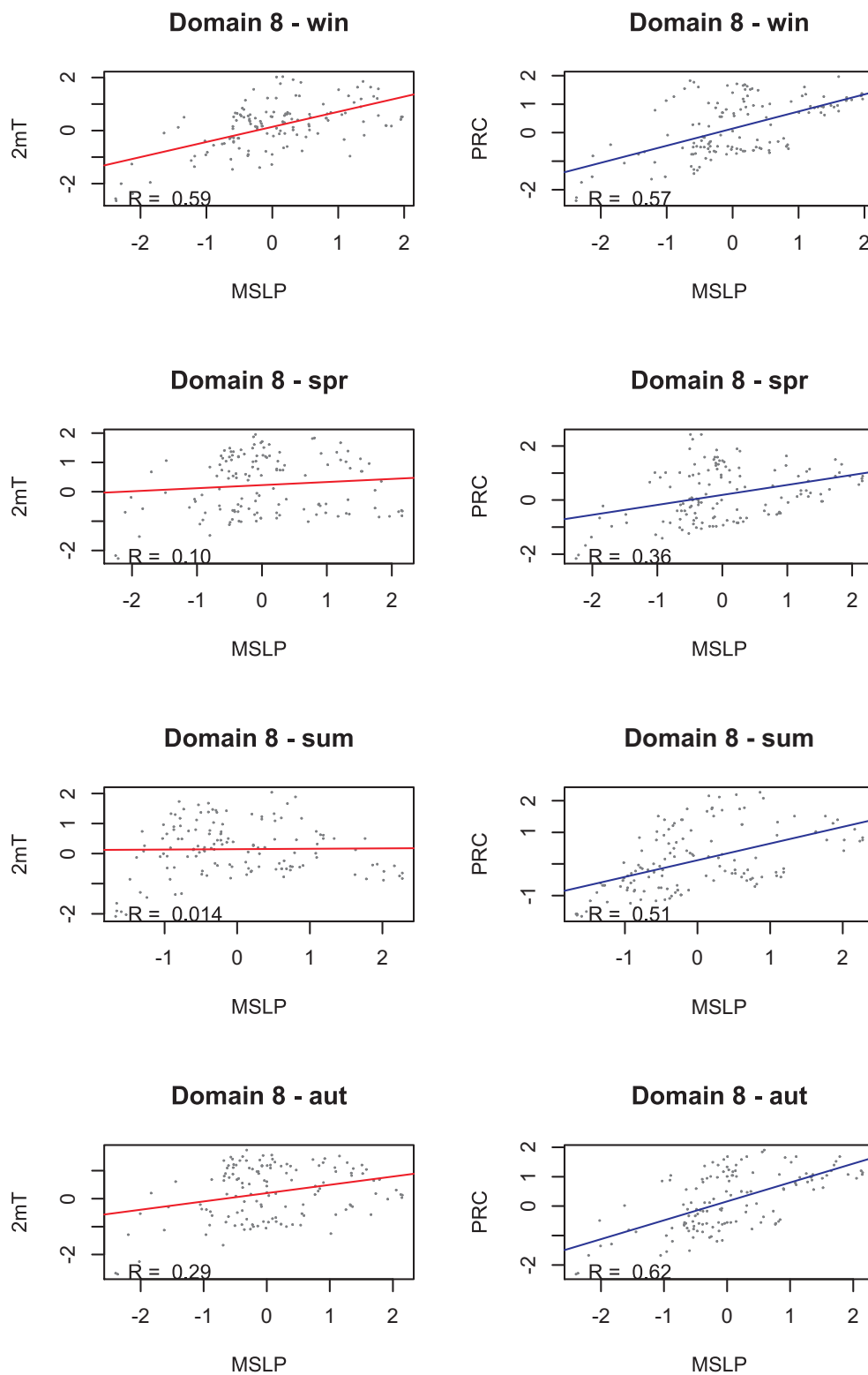


Figure 4.10: Same as Fig. 4.9 but for domain 8.

..... 4.2 Basic evaluations and comparisons of circulation type classifications

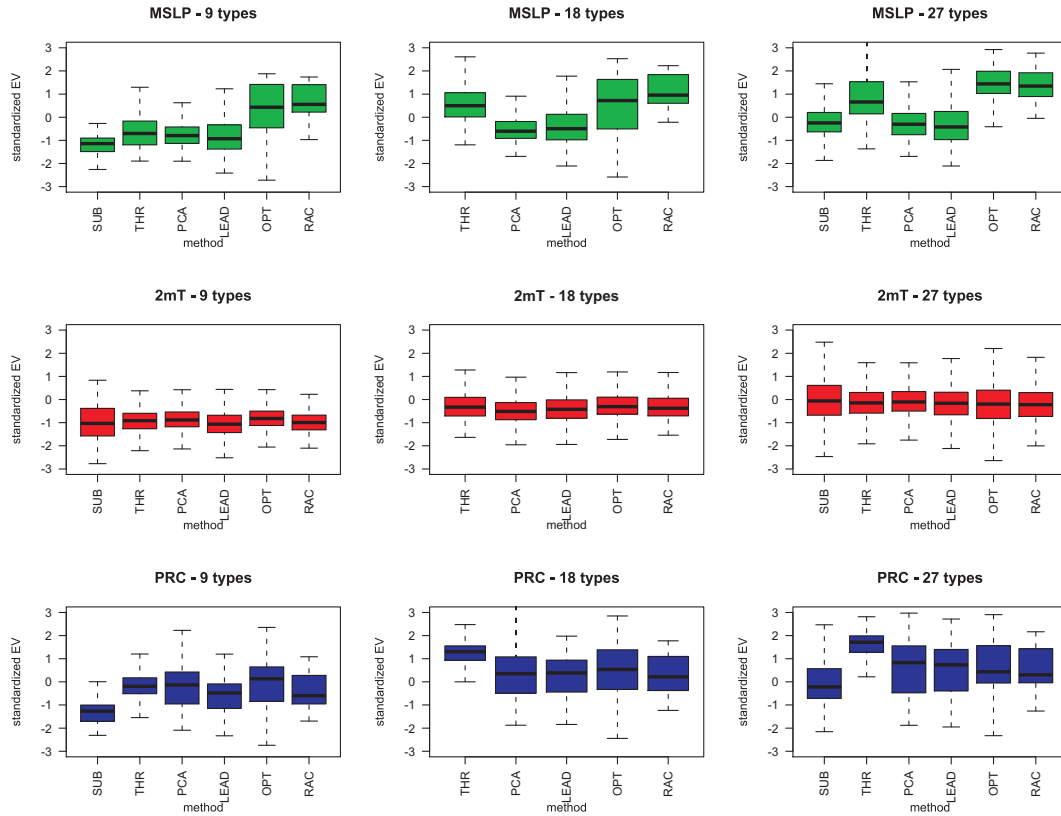


Figure 4.11: Boxplots of EV (determined for the period 1957–2002) estimated for all circulation type classifications from the COST733CAT-database, grouped according to basic method groups (x-axis categories in each plot), estimated for (rows from top to bottom) MSLP, 2mT and PREC and (columns from left to right) 9, 18 and 27 circulation types respectively. Upper/lower whiskers indicate the 1.5 interquartile range (IQR) from the upper/lower quartile.

From Fig. 4.11 it is obvious that there are distinct differences among the basic method groups concerning the performance for MSLP with the OPT- and RAC-methods reaching highest values of EV. However least for the 18- and 27-type variants THRES-methods reach comparable high EV values, whereas and LEAD methods feature distinctly lower performance. Less pronounced differences can be seen for 2mT and PREC. Most outstanding is the leading performance of the THRES methods for PREC.

Larger variations among the method groups not only for MSLP but as well for 2mT and PREC can be detected for selected individual spatial domains and when looking at different seasons (Figs. 4.12 and 4.13). Different method groups perform best in different domains, for different variables and in different seasons, hereby a leading performance for the one variable is not necessarily coupled with a high performance value for the other variables as well. OPT and RAC appear to be the best performing method groups for MSLP, followed by THRES.

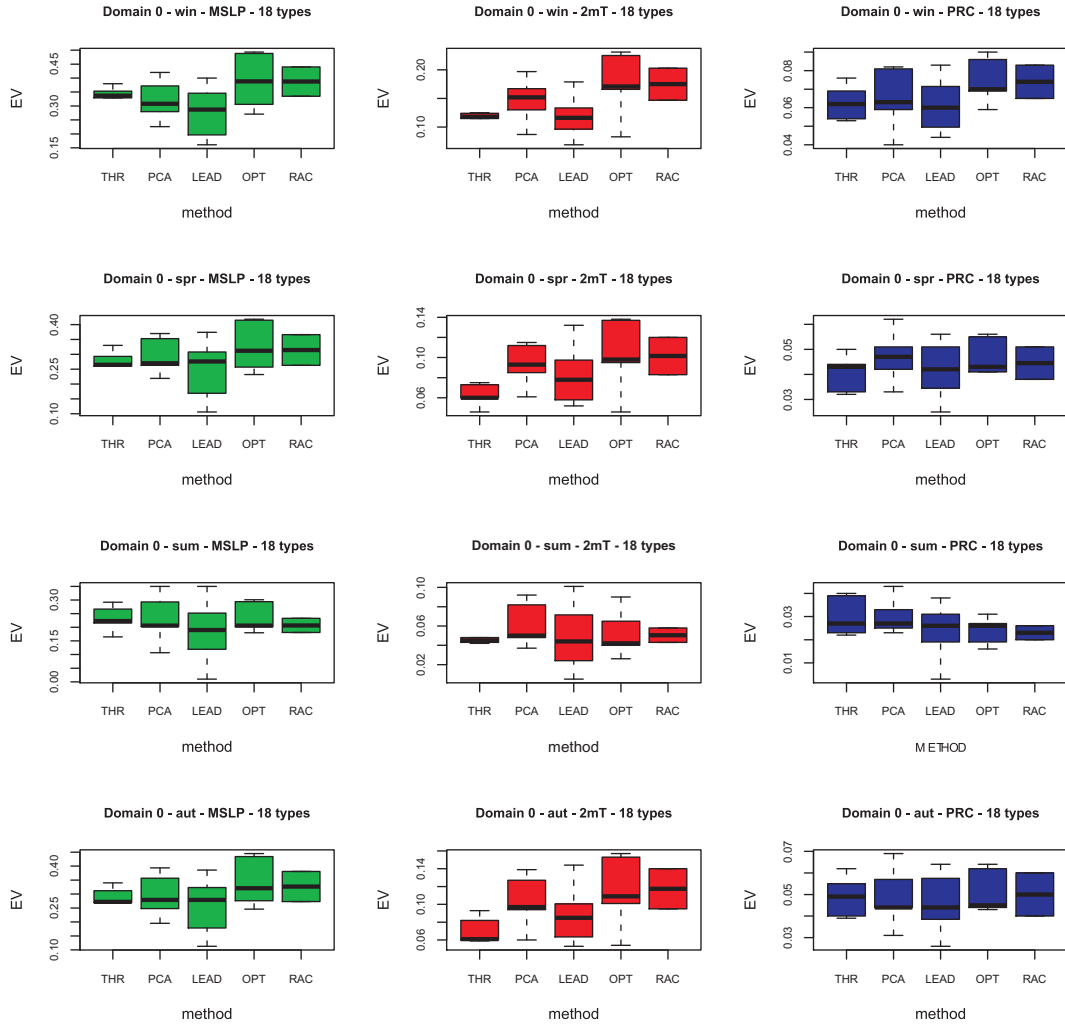


Figure 4.12: Boxplots of EV (determined for the period 1957–2002) estimated for circulation type classifications with 18 types (within a range of ± 3) from the COST733CAT-database for spatial domain 0, grouped according to basic method groups (x-axis categories in each plot), estimated for (rows from top to bottom) the three month seasons winter, spring, summer and autumn and (columns from left to right) the climatic target variables MSLP, 2mT and PRC respectively. Upper/lower whiskers indicate the 1.5 interquartile range (IQR) from the upper/lower quartile.

For 2mT it is not possible to name one leading method group because of highly variable results for subdomains and seasons. For PRC on the other hand it's possible to state that most often the THRES methods reach highest performance especially in the smaller subdomains. An overview including all spatial domains, seasons and target variables is provided in Figs. 4.14a and 4.14b.

Fig. 4.14a indicates for each domain, season and target variable, separately for different numbers of circulation types (a) the best performing basic method group (in terms of EV averaged over all CTCs from the respective method group) and Fig. 4.14a indicates the basic method group to which the best performing individual CTC belongs. From Fig. 4.14a it can be seen that although the pseudo random classifications (RAC) feature the highest mean performance (in terms of

..... 4.2 Basic evaluations and comparisons of circulation type classifications

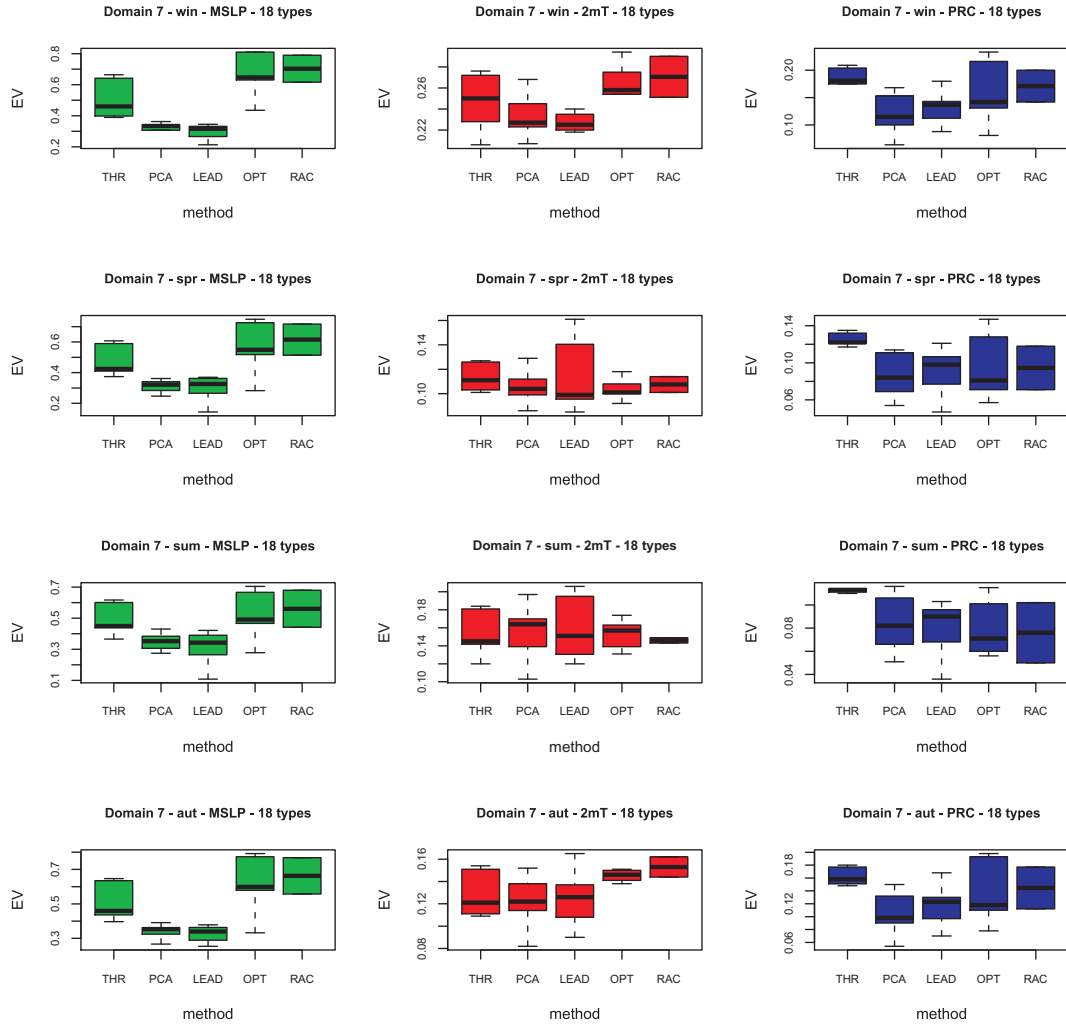


Figure 4.13: Same as Fig. 4.12 but for domain 7.

EV) for MSLP in almost all cases, CTCs from the OPT method group turn out to be the single best performing classification most cases. Concerning target variables 2mT and PREC there are striking differences between Figs. 4.14a and 4.14b: in many cases the single best performing classification does not belong to the basic group of methods featuring the highest mean performance level in the respective case. This appears most distinct for the THRES methods which show highest mean performance levels for PREC in most cases but only for a minority of cases as well provide the single best classification. As for MSLP the best performing classifications for PREC mainly stem from the OPT method group. For 2mT on the other hand there is a clear tendency towards higher performance related to the PCA and LEAD methods. Once more remarkable is the high performance of the SUB method group especially for 2mT and mainly for domains 4 to 7.

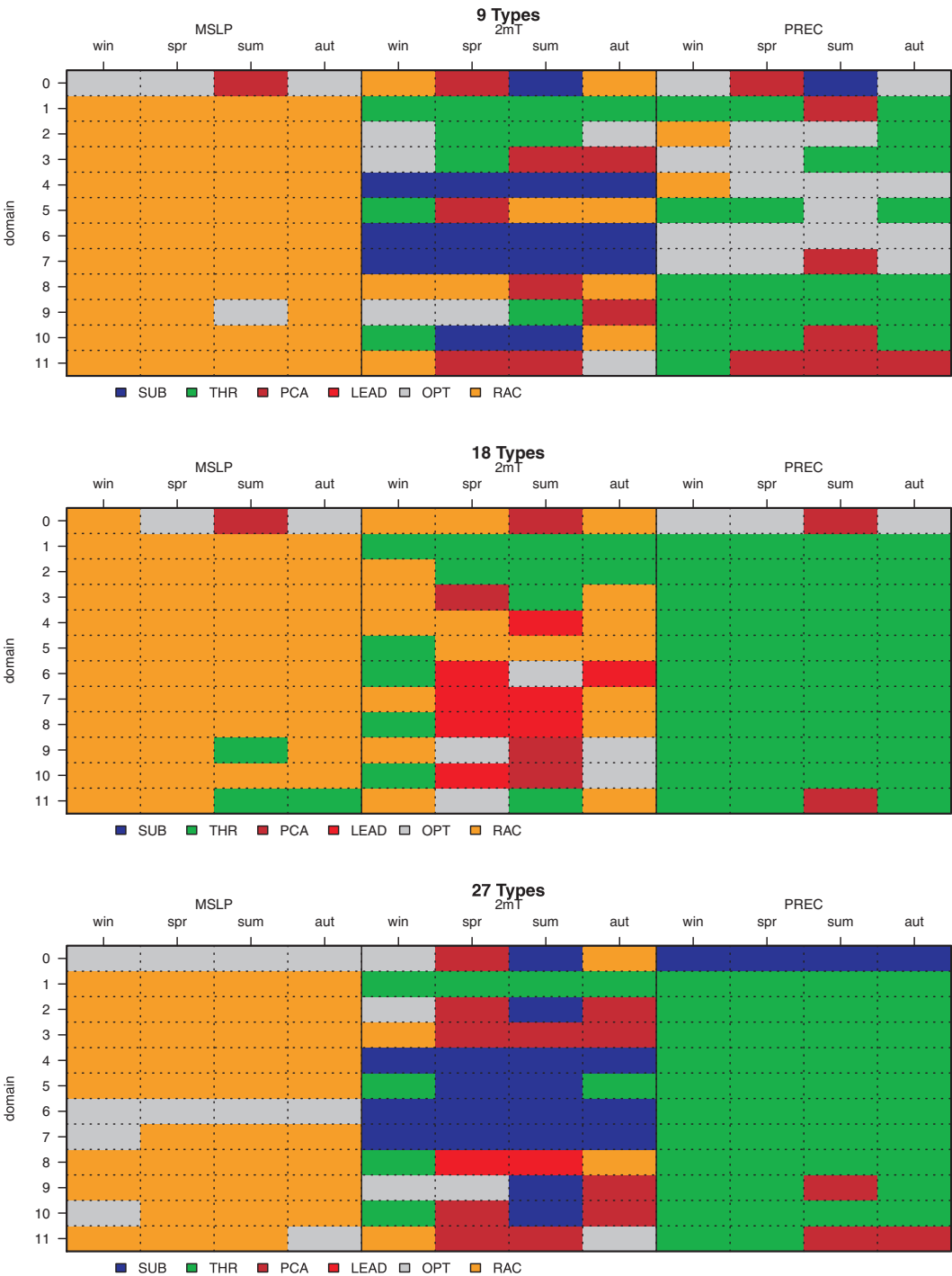


Figure 4.14a: Tables indicating best performing basic method groups of circulation classifications, in terms of EV averaged over all members of the respective method group. Separate tables are given for circulation classifications comprising 9 (top), 18 (center) and 27 (bottom) types. Each table provides an indicator on the best performing method group for each of the 12 spatial domains, for the three target variables MSLP, 2mT and PREC and for the 4 3-month seasons winter (DJF), spring (MAM), summer (JJA) and autumn (SON).

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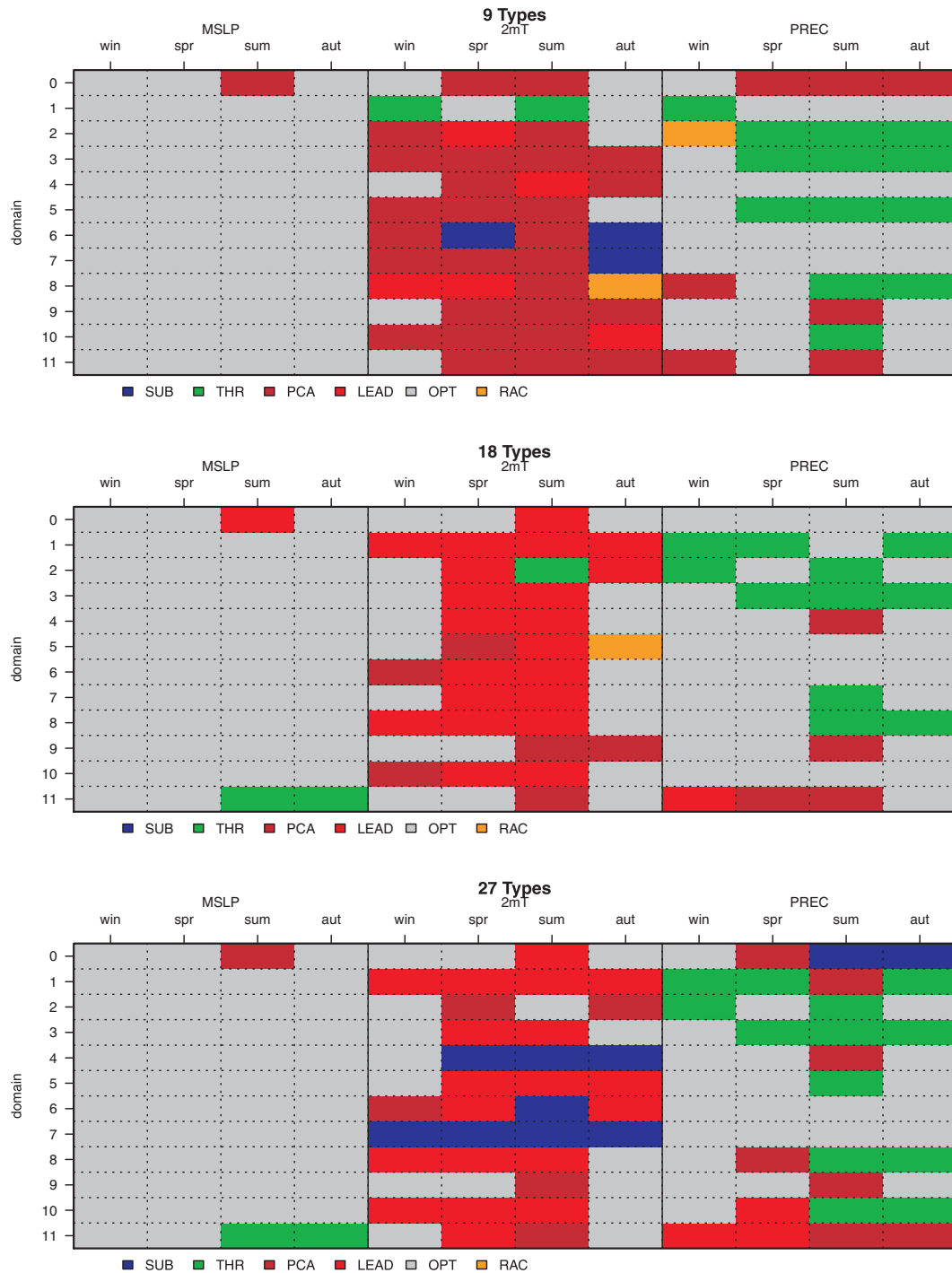


Figure 4.14b: Tables indicating the basic method group to which the best performing (in terms of EV) circulation type classification belongs. Separate tables are given for circulation classifications comprising 9 (top), 18 (center) and 27 (bottom) types. Each table provides an indicator on the method group of the best performing CTC for each of the 12 spatial domains, for the three target variables MSLP, 2mT and PREC and for the 4 3-month seasons winter (DJF), spring (MAM), summer (JJA) and autumn (SON).

4.2.3.6 CTC performance depending on sequence length

On the basis of an precursor version of the actual COST733CAT database (BECK and PHILIPP, 2010) stated that performance with respect to 2mT increased for a modification of the SNADRA classification that utilizes not single days but sequences of 4 days for classification. For the most recent version of the COST733CAT database such sequential variants are provided for several classification methods thus allowing for a more comprehensive comparison of single day versus sequential classifications. From Fig. 4.15 showing results of such comparisons for the three variables MSLP, 2mT and PREC it can be seen that the introduction of sequential classifications leads to a distinct improvement in performance (in terms of EV) only for 2mT and (not shown) most distinct in winter and autumn and for the LEAD methods (see Fig. 4.16). With respect to MSLP and PREC the single day classifications reach distinctly better performance in all seasons and for all method groups. Fig. 4.17 indicating the sequence length of the best performing CTC for each domain, season and target variable supports the finding that distinctly better performance related to the use of 4-day sequences is restricted to 2mT and appears most pronounced in winter and autumn.

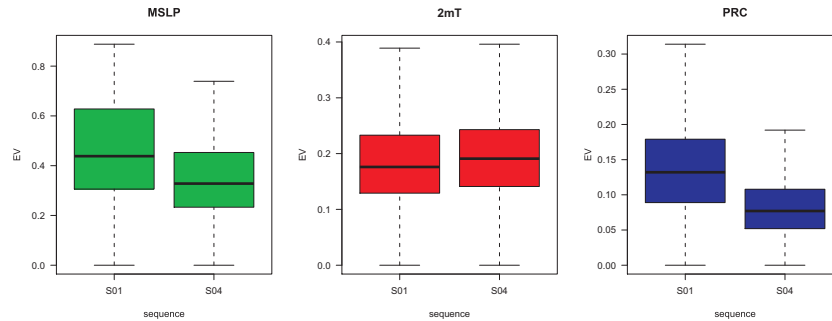


Figure 4.15: Boxplots of EV (determined for the period 1957–2002) for (left) MSLP, (center) 2mT, (right) PREC, estimated for circulation type classifications from the COST733CAT database, grouped according to the sequence length (1 day S01 or 4 days S04) used for classification. Only those classifications are included for which 1 day- and 4 day classification variants have been run. Upper/lower whiskers indicate the 1.5 interquartile range (IQR) from the upper/lower quartile.

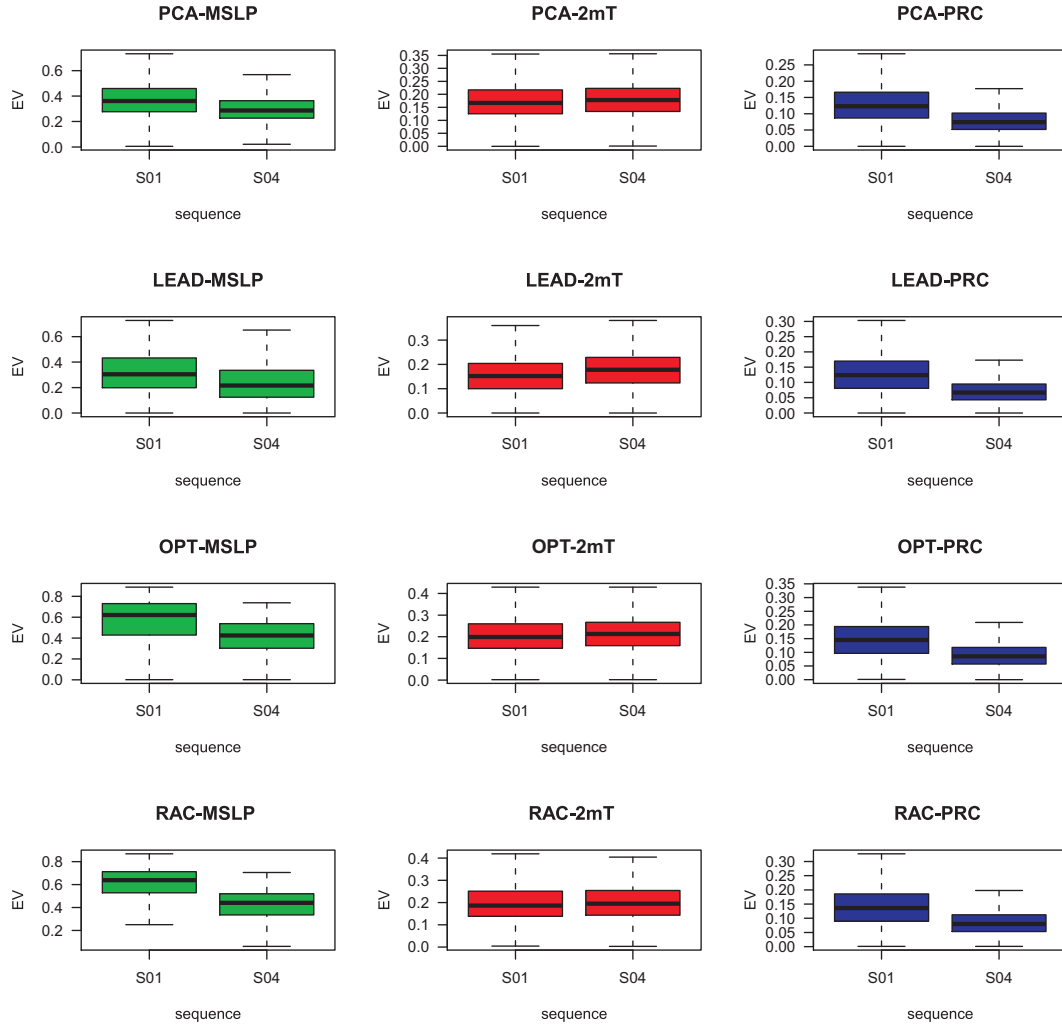


Figure 4.16: Boxplots of EV (determined for the period 1957–2002) for (left) MSLP, (center) 2mT, (right) PRC and (from top to bottom) four different basic method groups, estimated for circulation type classifications from the COST733CAT-database, grouped according to the sequence length (1 day S01 or 4 days S04) used for classification. Only those classifications are included for which 1 day- and 4 day classification variants have been run. Upper/lower whiskers indicate the 1.5 interquartile range (IQR) from the upper/lower quartile.

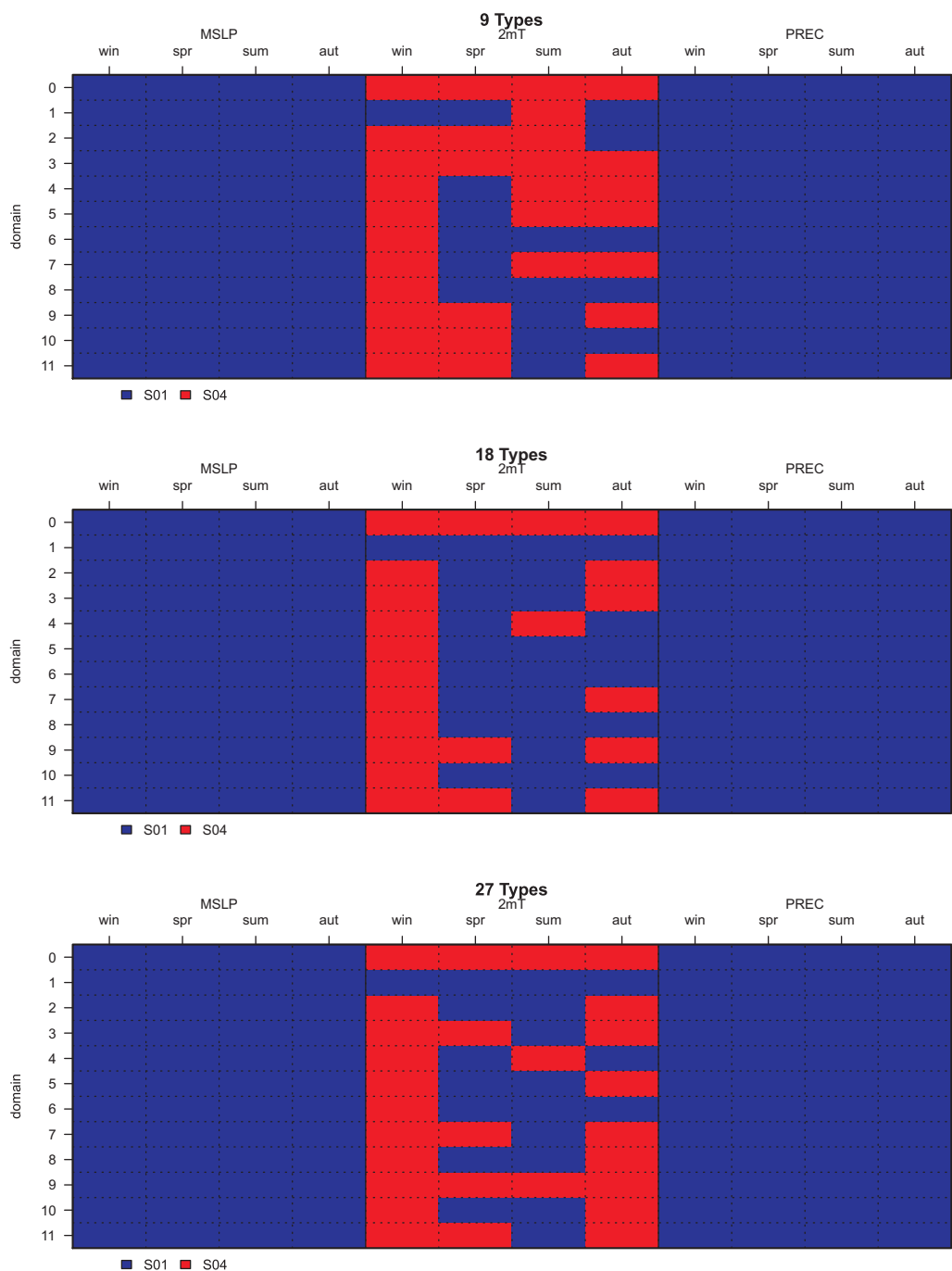


Figure 4.17: Tables indicating the sequence length of the best performing (in terms of EV) circulation type classification. Separate tables are given for circulation classifications comprising 9 (top), 18 (center) and 27 (bottom) types. Each table provides an indicator on the sequence length of the best performing CTC for each of the 12 spatial domains, for the three target variables MSLP, 2mT and PREC and for the four 3-month seasons winter (DJF), spring (MAM), summer (JJA) and autumn (SON).

4.2.3.7 CTC performance depending on temporal resolution

Another modification of the classification settings is the application of classifications to different temporal subsets (seasonal samples or the whole year). From Fig. 4.18 (a) it is clear that the seasonal classification approach leads to a reduction in performance concerning MSLP and 2mT and PREC as well. However when comparing the seasonal classifications to the annual variants comprising only 9 types the seasonal classifications feature superior performance for all three target variables [Fig. 4.18 (b)].

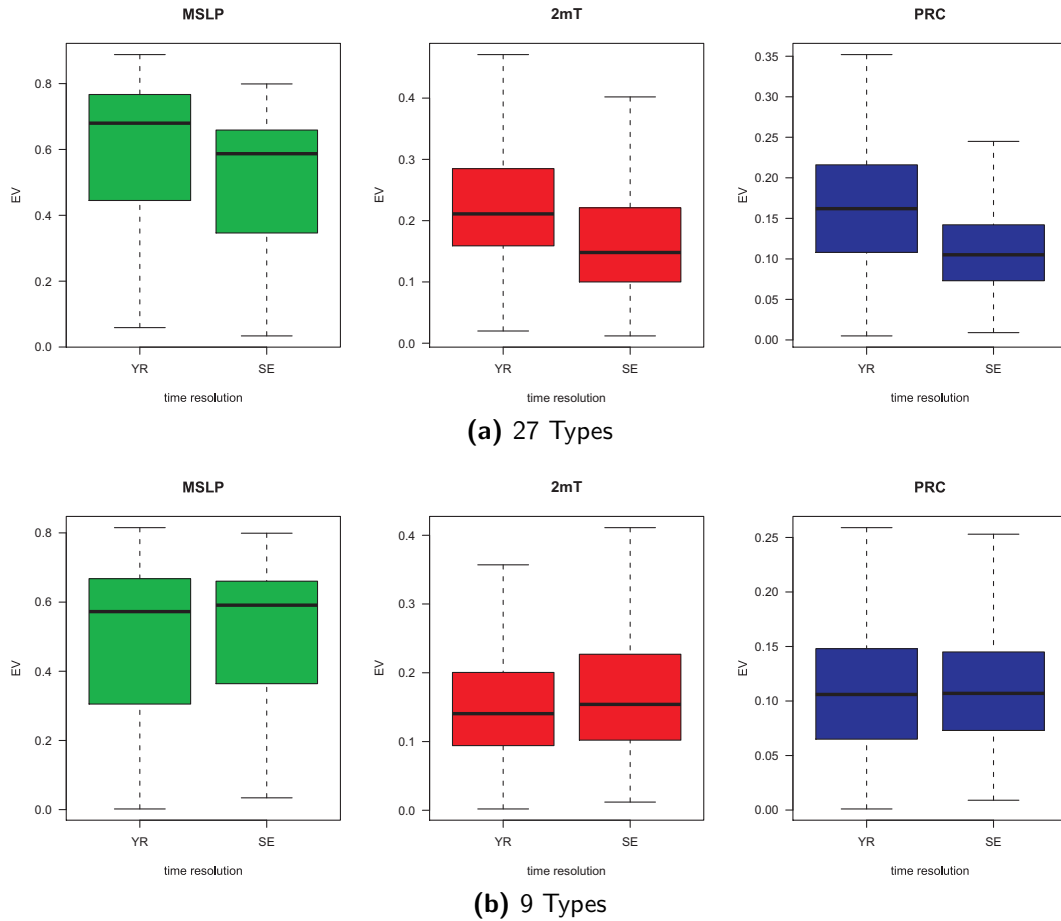


Figure 4.18: Boxplots of EV (determined for the period 1957–2002) for (left) MSLP, (center) 2mT, (right) PREC, estimated for circulation type classifications from the COST733CAT-database, grouped according to the temporal resolution (seasonal SE or annual YR) of the classifications. Only those classifications are included for which seasonal and annual classification variants have been run. Classifications using seasonal resolution comprising 28 (7 per season) types, annual classifications comprising 27 types – first row of boxplots, and 9 types – second row of boxplots. Upper/lower whiskers indicate the 1.5 interquartile range (IQR) from the upper/lower quartile.

4.2.3.8 CTC performance depending on different sets of input variables

Finally the inclusion of additional input variables into the classifications is analysed with respect to its influence on evaluation results. Fig. 4.19 illustrates performance

in terms of EV for variants of classifications using varying sets of input variables. Obviously the inclusion of additional variables improves performance for MSLP and especially 2mT no matter what variables are included. Best performance for 2mT is reached by combining SP with Z5, Y5 and K5. For PREC on the other hand only the inclusion of Y5 leads to a slightly general improvement in performance whereas the inclusion of other variables reduces performance levels. For the different method groups partly deviating results show up (for example only OPT methods achieve better performance for PREC by including Y5).

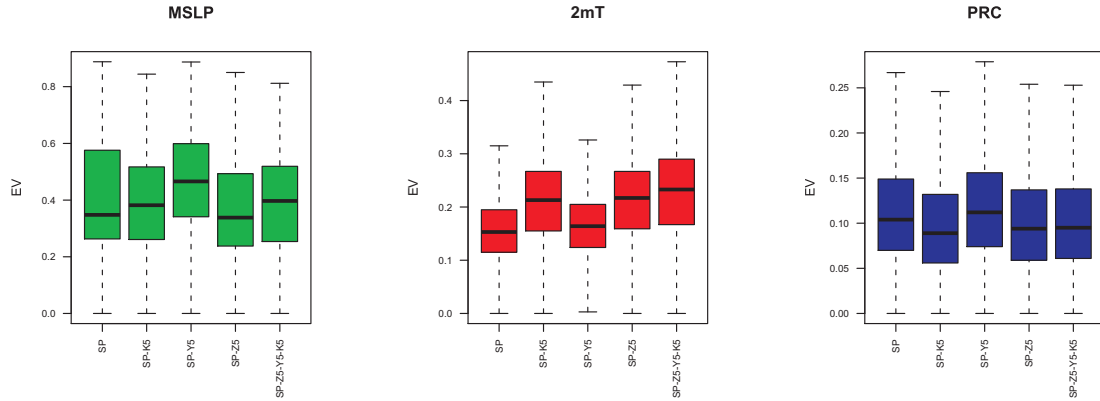


Figure 4.19: Boxplots of EV (determined for the period 1957–2002) for (left) MSLP, (center) 2mT, (right) PREC, estimated for circulation type classifications from the COST733CAT-database, grouped according to the number and combination of input variables used for classification. Only those classifications are included for which variants with all shown combinations of variables have been run. Upper/lower whiskers indicate the 1.5 interquartile range (IQR) from the upper/lower quartile.

Figs. 4.20a and 4.20b indicate for each domain, season and target variable, separately for different numbers of circulation types (a) the best performing set of input variables (in terms of EV averaged over all CTCs using the respective set of variables) and (b) the set of input variables which the best performing individual CTC utilizes. It can be seen that concerning MSLP the inclusion of the vorticity parameter Y5 leads to an increase in average performance for most domains and seasons. However interestingly when focusing on the single best performing classifications it turns out that these are often based only on SLP. Turning to the target variable 2mT it is obvious that the inclusion of additional variables leads not only to better mean performance in all cases but that also the best performing individual classification in (almost) all cases utilizes additional variables. Strikingly in winter and autumn the inclusion of K5 is mainly related to the increase in performance whereas in summer and spring the inclusion of all potential input variables (Z5, Y5, K5) leads to a further increase in performance. For PREC mainly the inclusion of the vorticity parameter Y5 leads to an increase in performance.

..... 4.2 Basic evaluations and comparisons of circulation type classifications

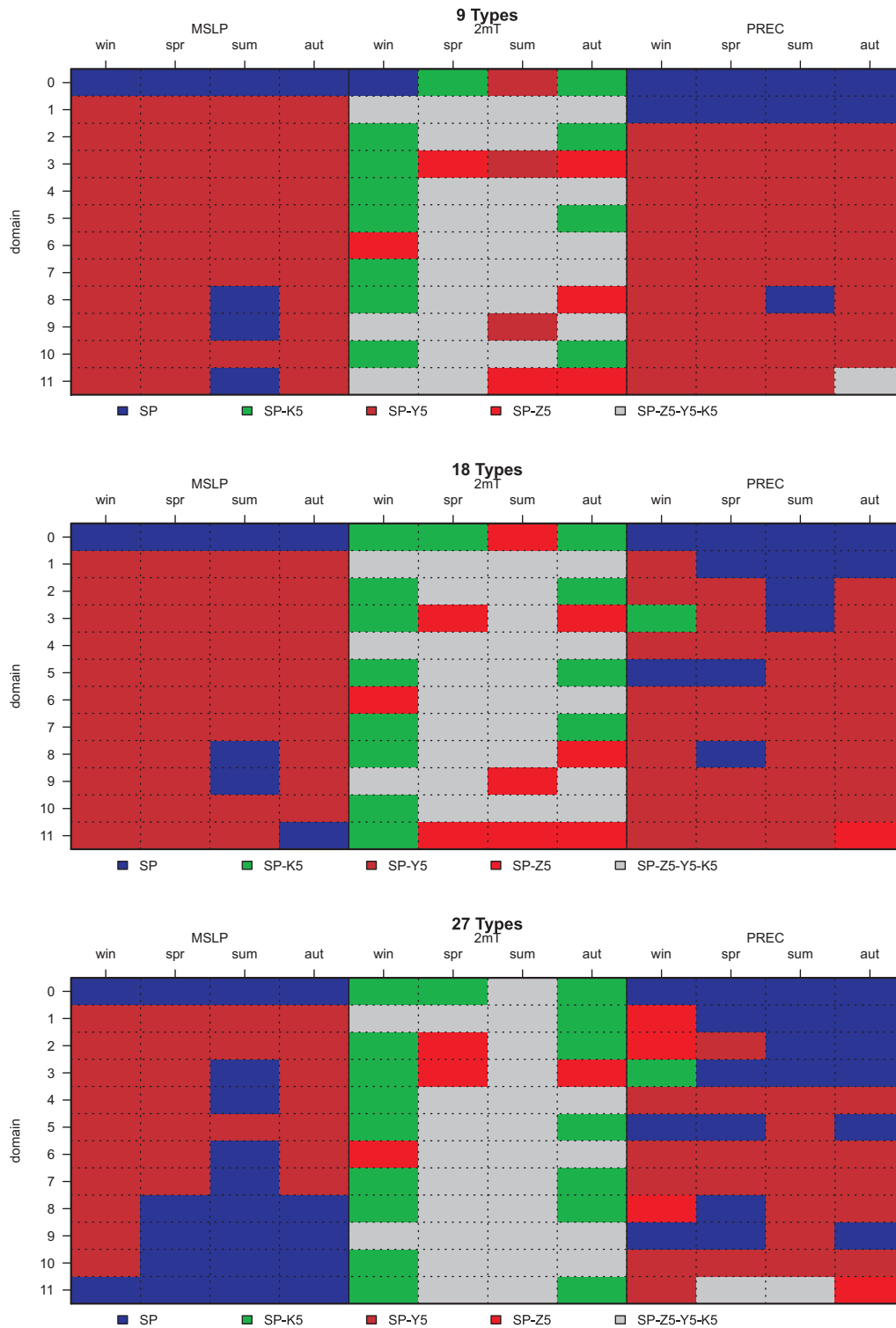


Figure 4.20a: Tables indicating the best performing selection of input variables, in terms of EV averaged over all individual CTCs using the respective set of input variables. Separate tables are given for circulation classifications comprising 9 (top), 18 (center) and 27 (bottom) types. Each table provides an indicator on the best performing selection of input variables for each of the 12 spatial domains, for the three target variables MSLP, 2mT and PREC and for the four 3-month seasons winter (DJF), spring (MAM), summer (JJA) and autumn (SON).

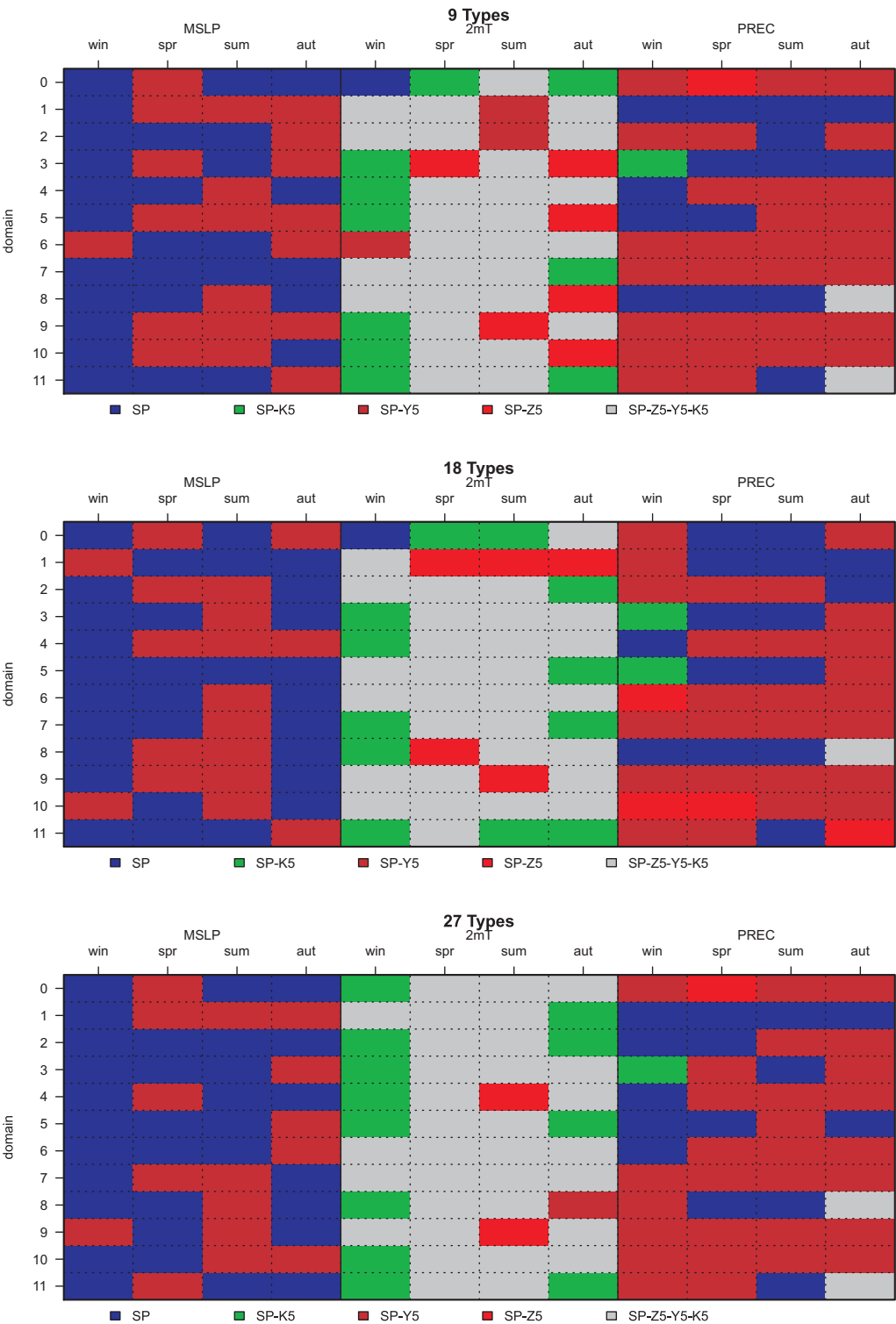


Figure 4.20b: Tables indicating the selection of input variables used by the best performing circulation classification, in terms of EV. Separate tables are given for circulation classifications comprising 9 (top), 18 (center) and 27 (bottom) types. Each table provides an indicator on the selection of input variables used by the best performing CTC for each of the 12 spatial domains, for the three target variables MSLP, 2mT and PREC and for the four 3-month seasons winter (DJF), spring (MAM), summer (JJA) and autumn (SON).

4.2.3.9 CTC performance for individual classifications

So far the performance of CTCs has been estimated for groupings of CTCs according to varying characteristics. In this section selected performance indices for individual CTCs will be presented. Again only a few selected examples from the whole set of available results is included in this report.

EV values averaged over all domains and all seasons are presented for CTCs with approximately 27 types in Fig. 4.21 on page 103. Figs. 4.22 and 4.23 (pages 104–105) illustrate *EV* for domain 0, and winter and summer respectively again for CTCs with around 27 types. Results for domain 7 are displayed in Figs. 4.24 and 4.25 (pages 106–107).

In all figures standardized *EV* values are sorted in ascending order (from left to right) thus each figure provides a ranking of individual classifications – from the worst to the best performing classification – for each sample as well.

It is not intended to discuss these figures in detail, instead just a few important general findings should be stated. From evaluation metrics (*EV*) estimated over all domains and seasons (Fig. 4.21) it can be seen that for MSLP [Fig. 4.21 (a)] CTCs from the OPT method group feature highest performance levels in terms of *EV*, whereas LEAD and PCA classifications exhibit mainly below average *EV* values. Various members of the THRES method group show different performance levels.

For 2mT and PREC however the leading position of the OPT classifications is not this pronounced. Concerning 2mT especially some LEAD classifications reach remarkable performance whereas for PREC also several THRES based CTCs show *EV* values that are comparable to those of the leading OPT methods. In this context it is worth mentioning that the THRES classifications reach such high performance levels only for their 18 and 27 type variants respectively, most probable due to the fact that only in these variants the THRES methods include a vorticity estimate that obviously increases skill for precipitation.

Concerning the several modifications introduced in the most recent version of the COST733CAT database (sequential classification, seasonal classification, additional input variables) it is worth mentioning that only for 2mT sequential classifications and classifications using additional input parameters lead to somewhat systematically better performance. That's not only true for the average performance over all domains and seasons but as well for the individual domains and for the two seasons winter and summer as well.

With respect to results for domain 0 (Figs. 4.22 and 4.23) it is remarkable that especially during summer and for 2mT and PREC classifications from other method groups than OPT reach best performance. This includes in particular the subjective OGWo classification showing best performance for PREC in summer. This effect can be seen for the smaller domain 7 (Figs. 4.24 and 4.25) as well however most distinct for PREC in summer.

Taking into account the results for all domains (not shown here) it becomes clear that it is not possible to name one single best classification. Depending on the domain, the season and the target variable different classifications from

different method groups turn out to be the best performing approaches. However such summaries as given in Figs. 4.21–4.25 can help in giving a first advice on what classification performs well under which circumstances.

Caption for Figure 4.21 on page 103

Standardized EV for circulation type classifications from the COST733CAT-database with 27 types (within a range of ± 3). Estimated over all spatial domains and all seasonal subsets. For (a) MSLP, (b) 2mT and (c) PREC. Colours of bars indicate basic method groups, symbols indicate classification variants according to sequence length (1 day/4 days), temporal resolution (seasonal/annual) and type/number of input variables (only classifications using solely SLP are marked).

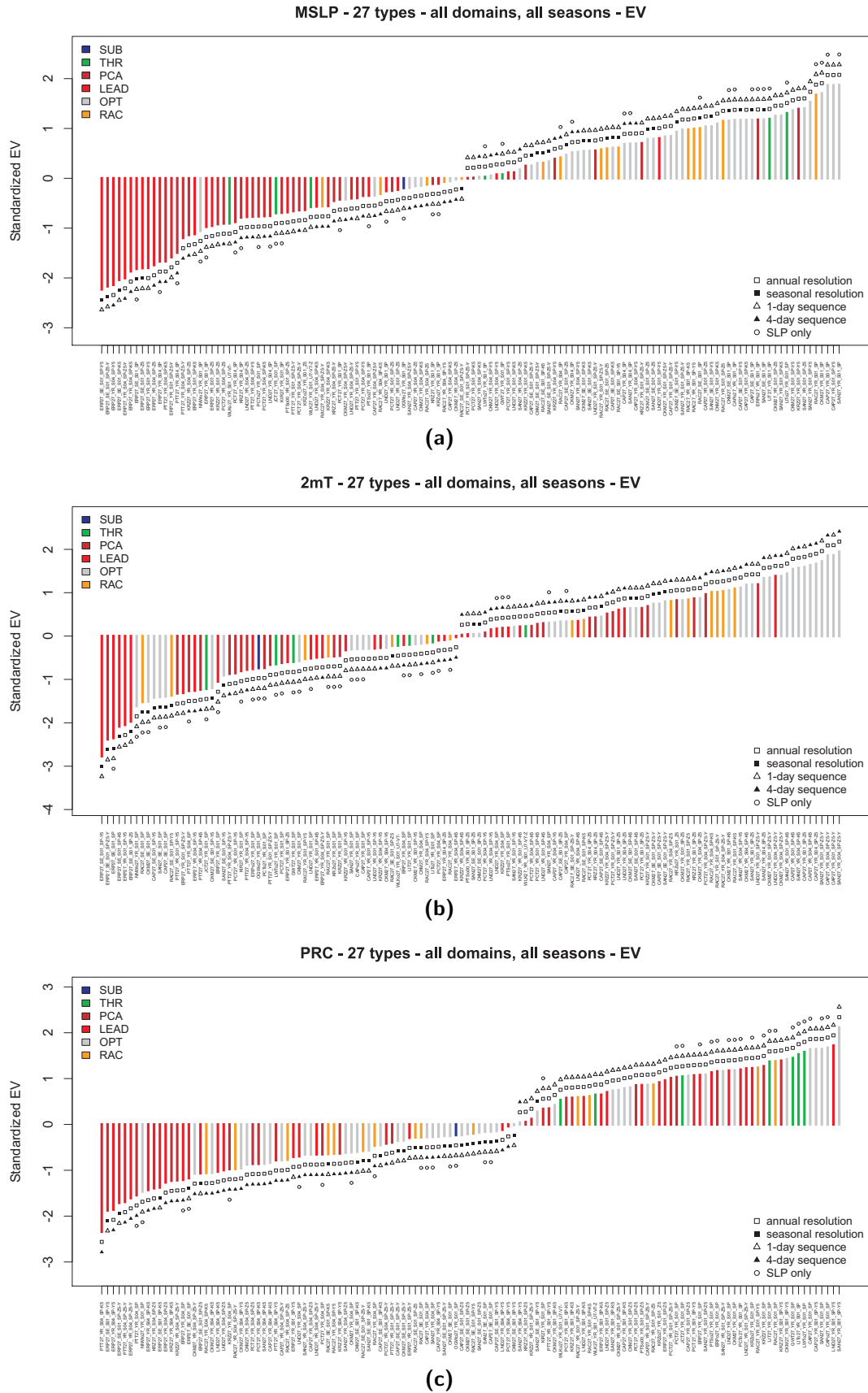


Figure 4.21: Caption – see bottom of page 102

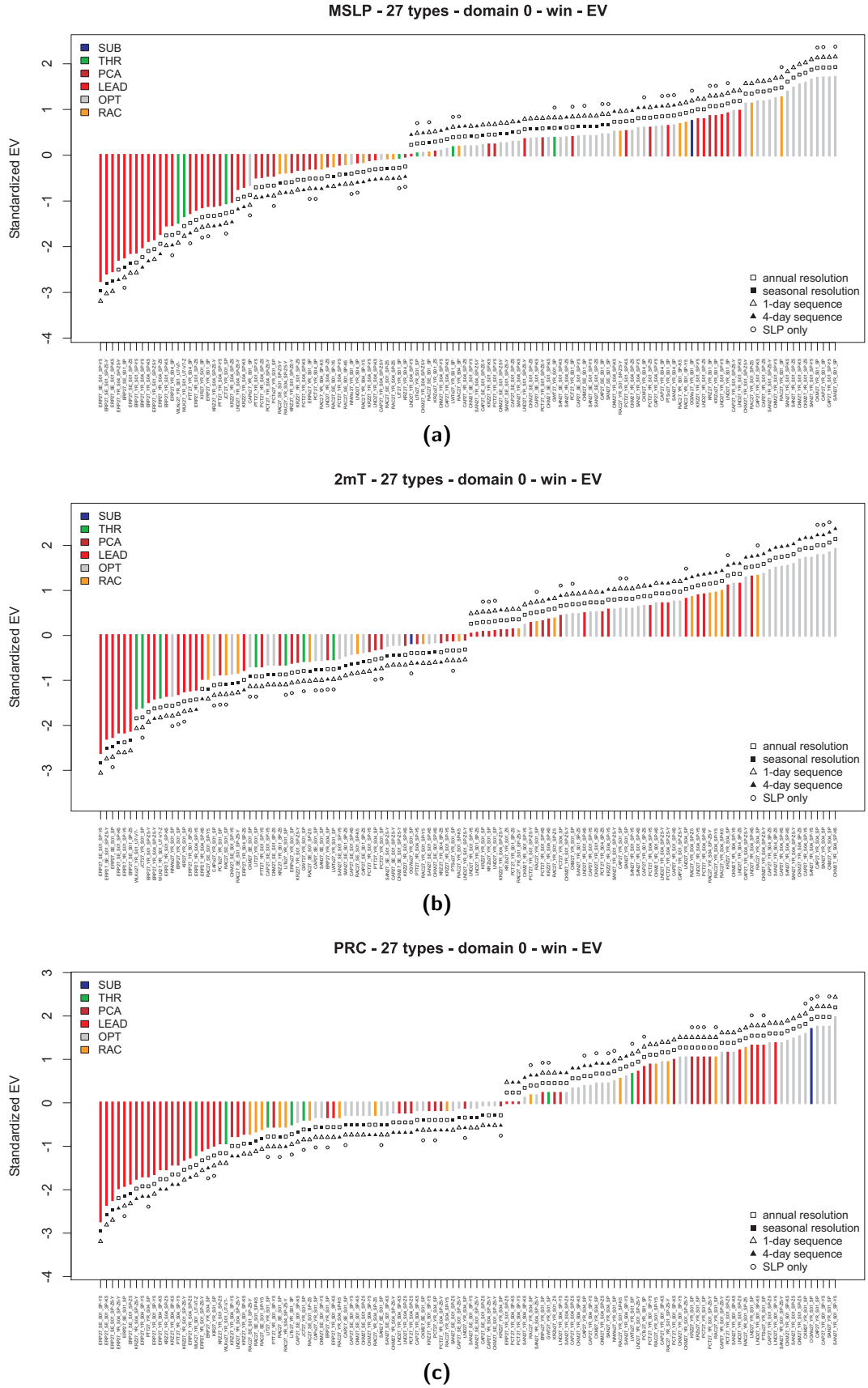


Figure 4.22: Same as Fig. 4.21 but for domain 0, winter (DJF).

..... 4.2 Basic evaluations and comparisons of circulation type classifications

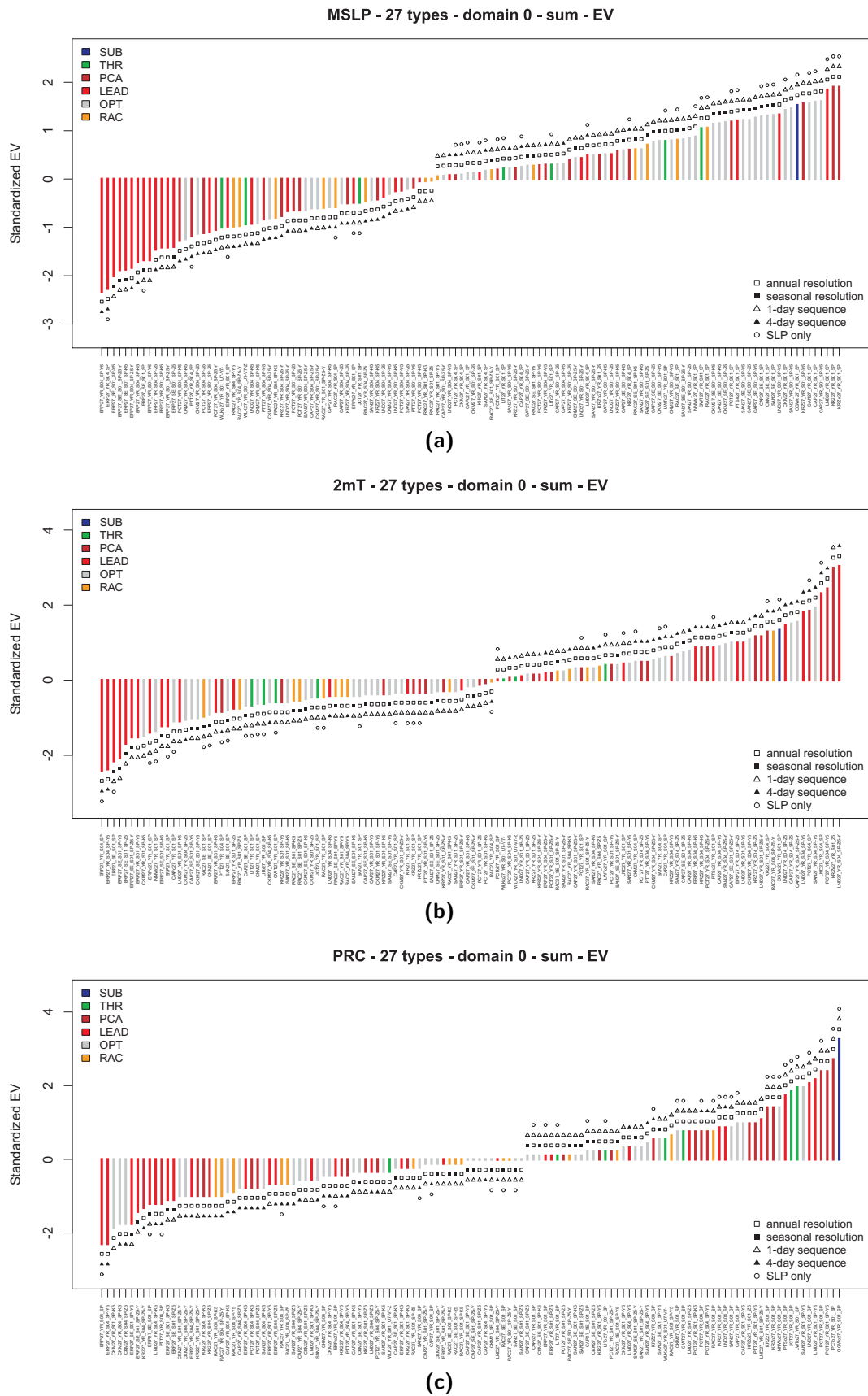


Figure 4.23: Same as Fig. 4.21 but for domain 0, summer (JJA)

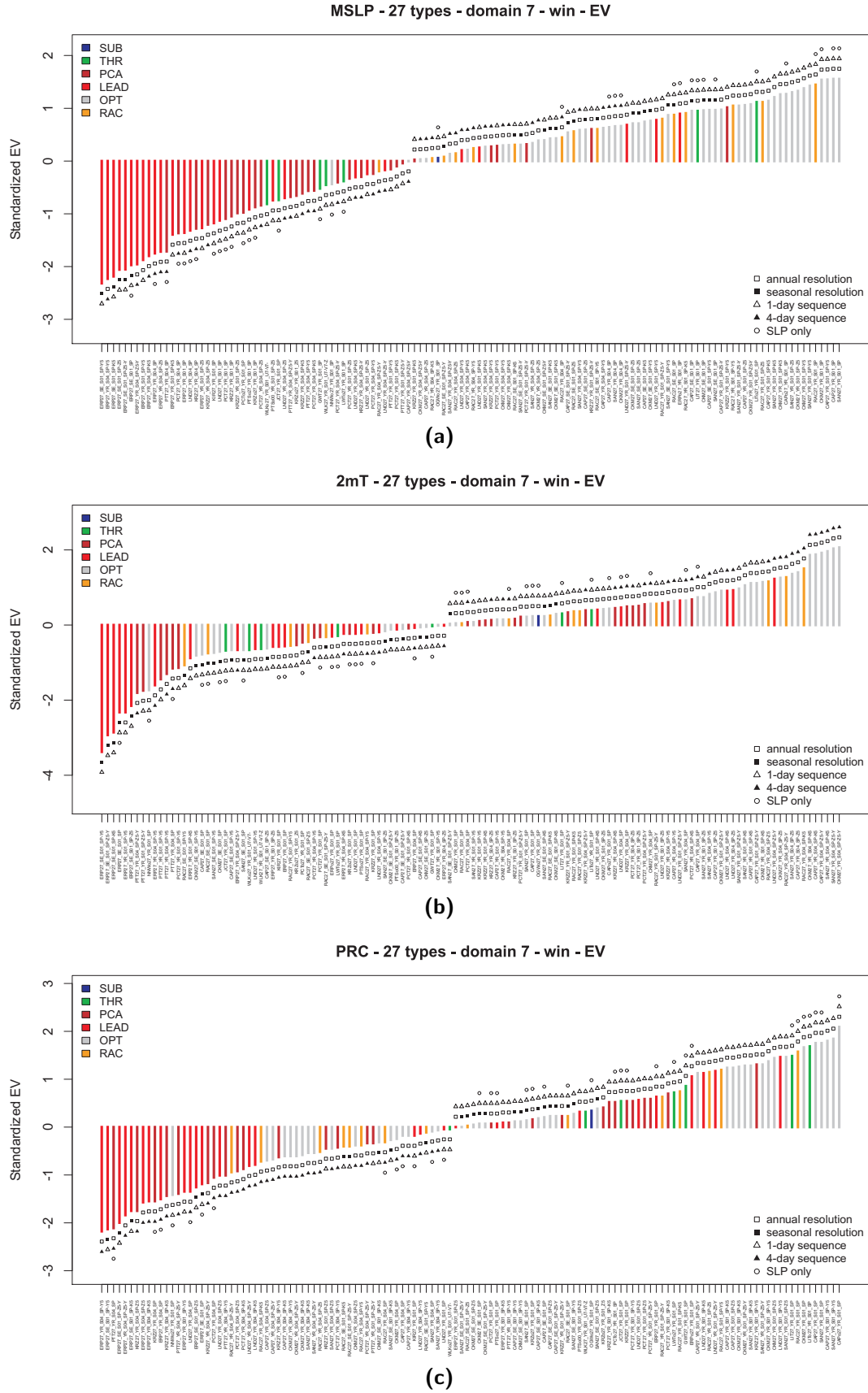


Figure 4.24: Same as Fig. 4.21 but for domain 7, winter (DJF)

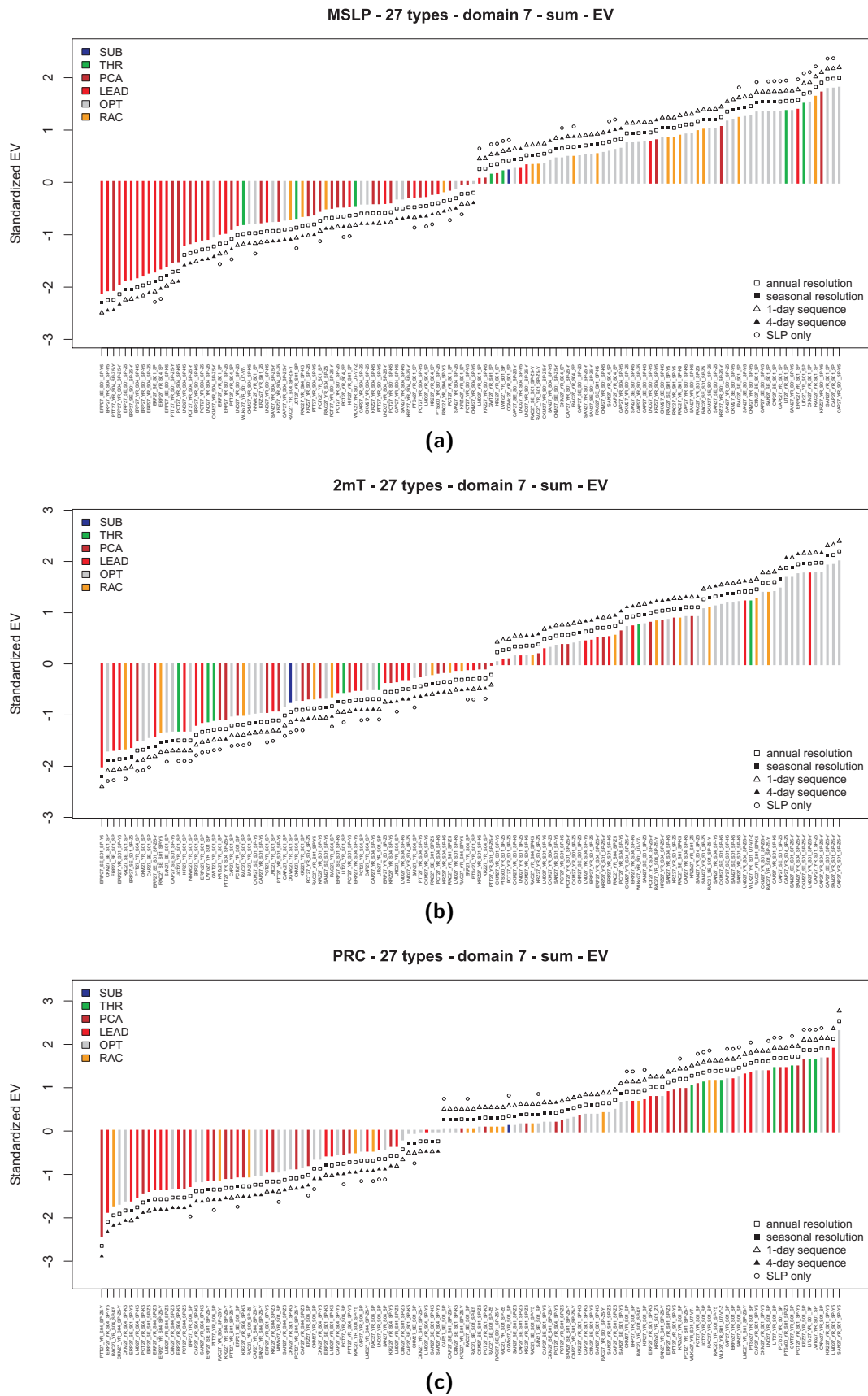


Figure 4.25: Same as Fig. 4.22 but for domain 7, summer (JJA)

4.2.3.10 Spatial variations in CTC performance

In addition to evaluation results that are integrated whole spatial domains it has been analysed by [BECK and PHILIPP \(2010\)](#) as well in how far the performance of CTCs varies within individual spatial domains. Figs. 4.26a and 4.26b show fields of EV for the three target variables MSLP, 2mT and PREC for four selected CTCs – each of them representing one basic classification approach – for the Central European domain 7 for (a) winter and (b) summer. Minimum, mean and maximum of EV (in %) are indicated on the top left of each map.

With respect to MSLP the cluster based SANDRA method does not only reach by far the highest EV values (maximum value of 92%) but moreover exhibits the most extended region with distinctly high EV values over the whole domain. However the superior performance of SANDRA for MSLP does not equally apply to the surface climate variables 2mT and PREC.

For 2mT and PREC highest performance in terms of maximum values of EV is reached in winter and – concerning the spatial distribution – in western and northwestern parts of the domain. These general seasonal and spatial variations reflect more the general climate characteristics of Central Europe than performance characteristics of individual CTCs. Western and northwestern parts of the domain which are more exposed to more frequent western and northwestern circulation types and thus exhibit a closer relationship between surface climate conditions and large-scale circulation. Seasonal variations on the other hand are due to the fact that surface climate in winter is mainly controlled by macro-scale circulation whereas in summer – and especially for precipitation in the more continental parts of Europe – small scale processes (e.g. local convection) are more relevant for temperature and precipitation variability on the synoptic time-scale. Differences in spatial performance patterns of the four selected CTCs for 2mT appear for winter and more pronounced for summer with respect to maximum values of EV and as well concerning the spatial configurations. Spatial performance patterns for PREC show even more distinct differences between CTCs. All in all the analyses of spatial patterns of CTC performance for climatic target variables 2mT and PREC do not clearly indicate a generally superior performance of one CTC. Instead the comparison of the four selected CTCs concerning 2mT and PREC points to some specific “core regions” of higher performance related to individual CTCs.

Comparing such spatial performance patterns of all available CTCs for one domain it is possible to identify for each individual grid point the best performing CTC for each of the three target variables MSLP, 2mT, PREC. Examples of resulting maps – again for spatial domain 7 – are given for summer and winter in Fig. 4.27. For each grid point the best performing CTC in terms of EV is indicated and an additional indicator for the prominence of the leading CTC is given (see [BECK and PHILIPP, 2010](#), for details).

As main result from Fig. 4.27 it can be stated that only a few CTCs are selected as the “best” methods with respect to MSLP whereas a variety of leading CTCs appear on respective maps for 2mT and PREC. Remarkably CTCs from the THRES group of methods feature clearly prominent EV values especially in the central parts of the domain, which is due to the inclusion of a vorticity estimate (derived from MSLP) in both CTCs.

(Continued on page 112)

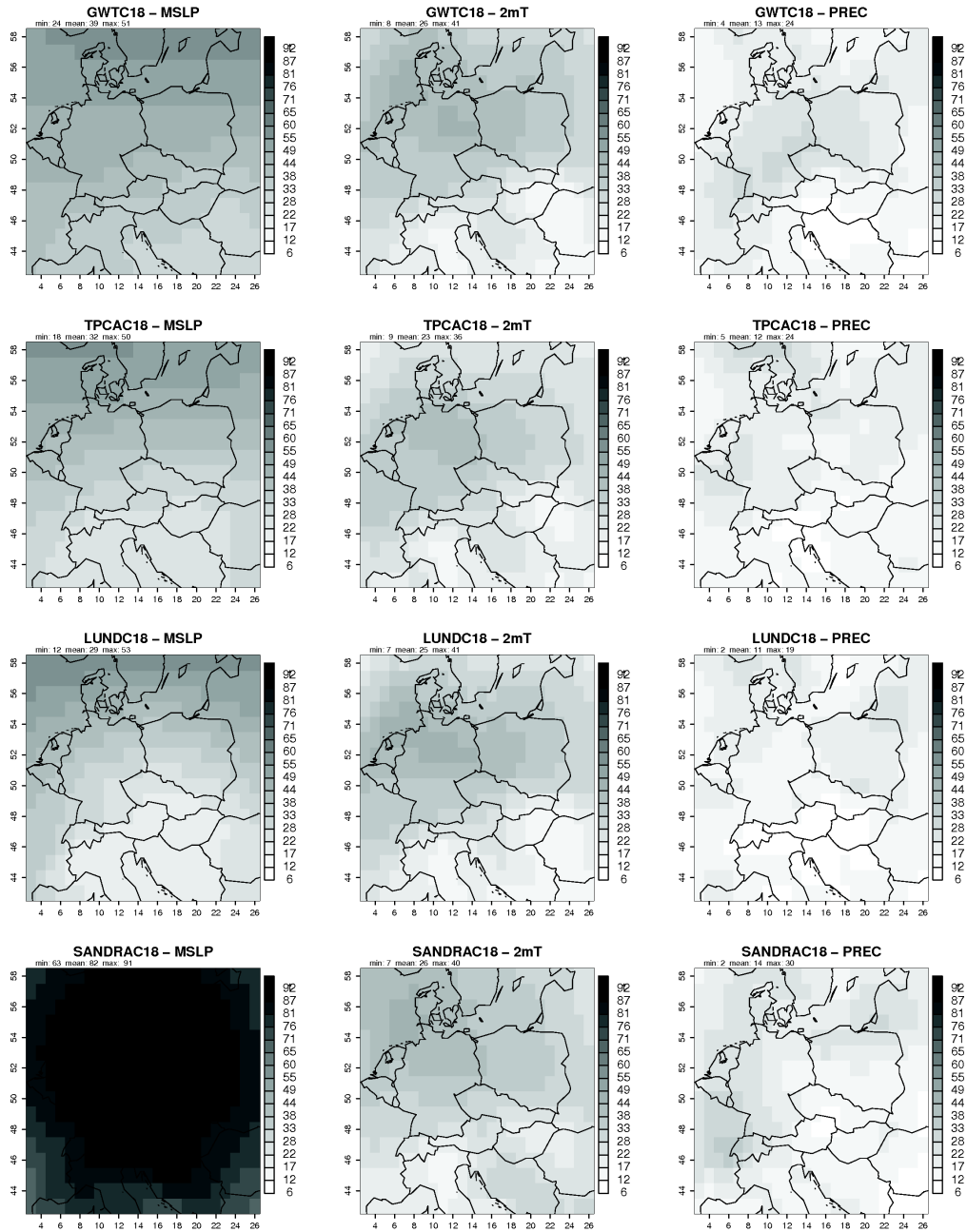


Figure 4.26a: Spatial distribution of EV (in %) for winter (DJF, 1957–2002) over spatial domain 7 for MSLP, 2mT and PREC respectively. For selected circulation type classifications from the COST733CAT-database. Minimum, mean and maximum of EV (in %) are indicated on the top left of each map (from [BECK and PHILIPP, 2010](#)).

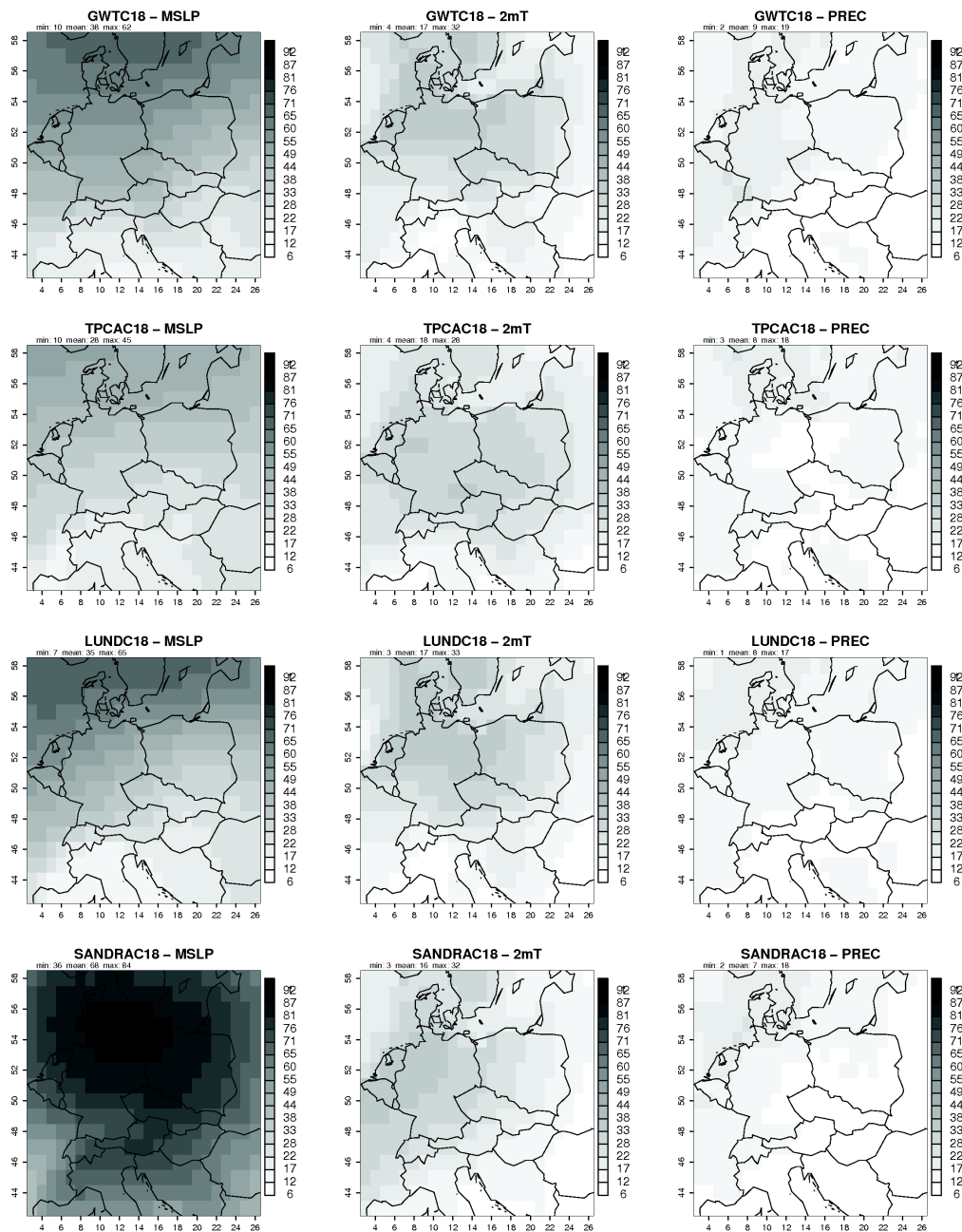


Figure 4.26b: As in Fig. 4.26a but for summer (JJA, 1957–2002).

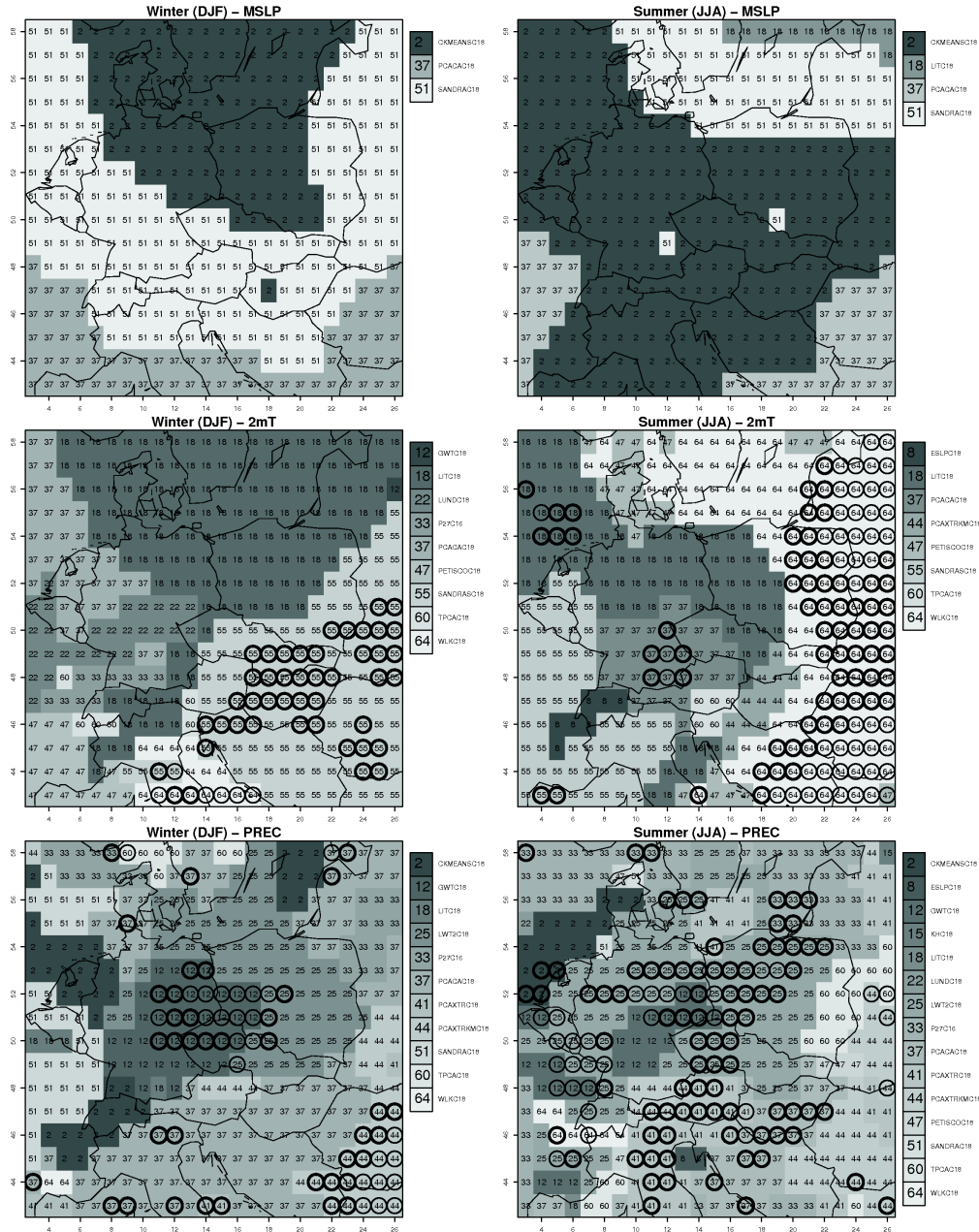


Figure 4.27: CTCs with highest performance (in terms of EV) at individual grid points in spatial domain 7. For MSLP, 2mT and PREC, in winter (DJF 1957–2002) and summer (JJA, 1957–2002). Circles indicate gridpoints for which EV of the leading CTC is higher than 1.5 times the interquartile range (IQR) above the third quartile (thin outline circle) and the EV of the following CTC is lower than 1.0 times the IQR above the third quartile (bold outline circle), (from [BECK and PHILIPP, 2010](#)).

The same analyses performed for three subperiods (1957–1977, 1970–1990 and 1982–2002; not shown) lead to very similar results, again pointing to the temporal stability of evaluation results (BECK and PHILIPP, 2010). The presented results strongly support the finding that superior performance of a specific CTC or a group of methods for MSLP is not necessarily related to a equally good performance for 2mT and/or PREC.

4.2.3.11 Evaluation of CTC performance by comparison with pseudo random classifications

In addition to the comparison of evaluation results for individual CTCs and for groups of CTCs delineated on the basis of varying parameters (basic method, temporal resolution, input parameters, ...) an evaluation of the CTCs included in the COST733CAT database has been performed by comparing the evaluation results for the deliberate CTCs with respective results for a sample of so called pseudo random or Random Centroid classifications (RAC, see Chapter 3 for a description). The motivation for such comparisons is to examine whether the deliberate choice of a specific classification method has a detectable effect on performance characteristics.

To this end the explained variance EV for 2mT and PREC has been calculated for deliberate circulation type classifications and as well for samples of 1000 pseudo random classifications that are available for each spatial domain. Subsequently EV values of individual deliberate classifications are compared with empirical EV distributions of pseudo random classifications using the exceedance of the 95th percentile of EV values from pseudo random classifications as an indicator for an enhanced performance of classifications.

Fig. 4.28 shows results of such comparisons for two selected domains (0 and 7), for the whole year and for CTCs with around 27 types.

For 2mT it becomes apparent, that in both domains only a few methods feature EV values exceeding the 95th percentile of the pseudo random classifications. Taking into account results for all spatial domains (not shown) it turns out that there is no single method which is better than the 95th percentile of the pseudo random classification in all spatial domains. However some methods show enhanced performance in many cases like LIT27 (Litynski) or PTSo27 (Petisco). Respective results for PREC are quite similar, i.e. no method reaches higher EV values than the pseudo random classifications in general. However again some methods exceed the 95th percentile of the explained variance of the pseudo random classifications more often than others.

Performing such comparisons on a monthly basis for all individual domains and summing up the resulting exceedances of the respective 95th percentiles of the pseudo random classifications for each deliberate classification provides an estimate of the overall performance of each classification method. Fig. 4.29 shows the fraction of exceedances of the 95th percentiles of the pseudo random classifications for a selection of deliberate classification methods for the two target variables 2mT and PREC and for different numbers of types (9, 18, 27).

For 2mT and as well for PREC only a small number of classifications (6 out of 31 at a maximum) reach exceedance frequencies of more than 50%. Thereby classifications from the THRES group of methods and from the OPT group of methods reach or exceed the 50% threshold more frequent than classifications from the remaining method groups. Remarkably it seems that methods that are applying some kind of data compression or filtering (e.g. initial PCA, pressure gradient indices, ...) during classification show a

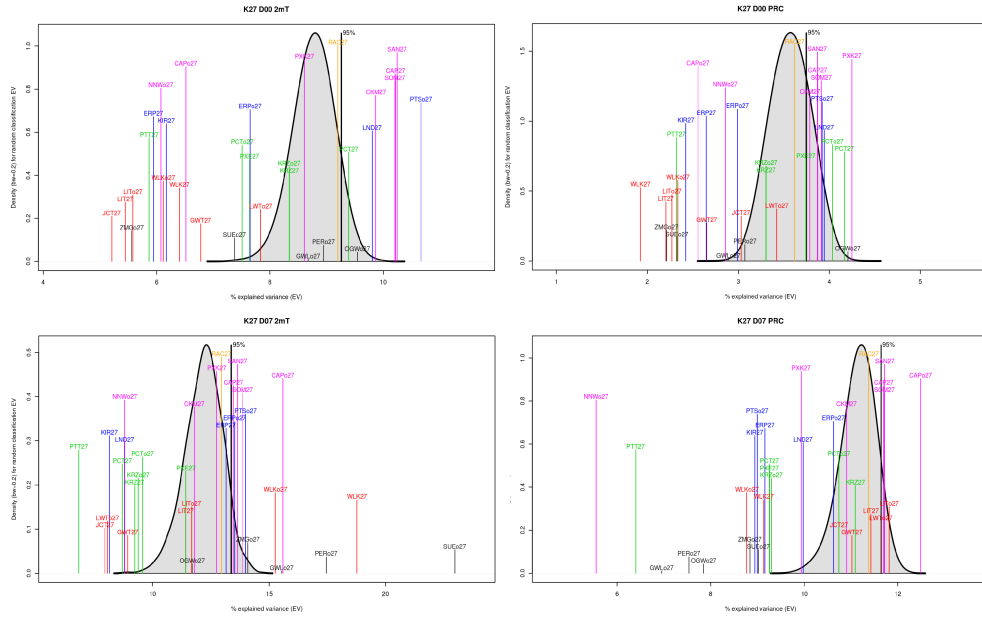


Figure 4.28: Density plots of EV for (left) 2mT and (right) PREC of pseudo random classifications (grey) compared to the explained variances of the deliberate methods from the COST733CAT-database (coloured vertical lines, height of line has no meaning, colors refer to method groups). Only values for classifications with around 27 types for domains 0 and 7 and the whole year are shown. The 95th percentile of the RAC values is denoted by a black line.

tendency towards higher performance levels than methods utilizing the whole set of grid point data for classification. Concerning the number of types, for 2mT the number of exceedances is higher for classifications with higher number of types (18 and 27) whereas for PREC the lowest number of exceedances turns out for 27 type classifications.

All in all Pseudo random classification seems to be a useful method for testing deliberate methods concerning their skill to discriminate target variables in circulation-to-environment approaches. In the given examples from the COST733CAT database it turns out that only a few classifications show a tendency towards a generally better performance than the pseudo random classifications.

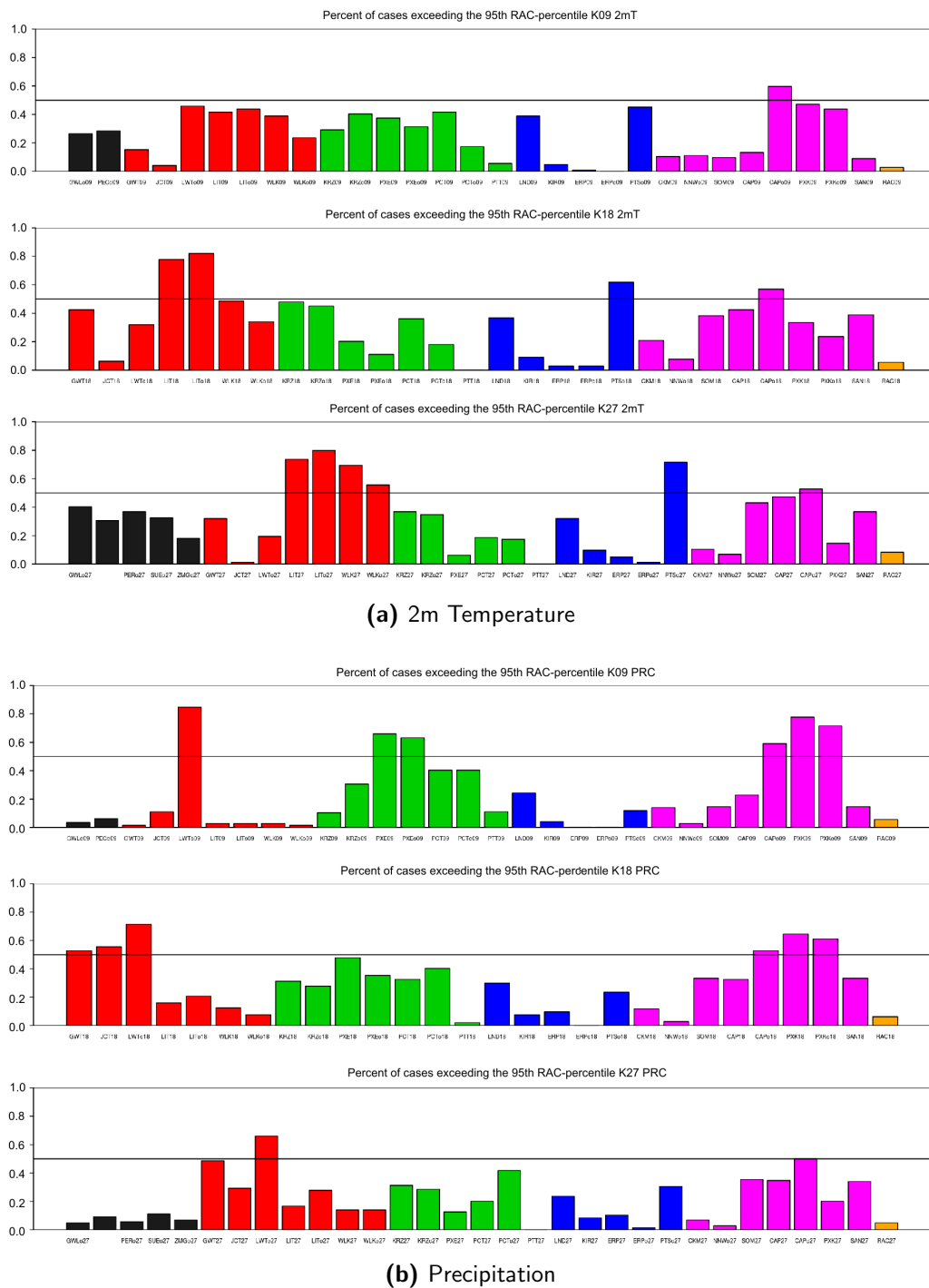
WG 3: *Evaluation and comparison*

Figure 4.29: Number of cases exceeding the 95th percentile of the explained variances of the pseudo random RAC-classifications for the deliberate methods, for (a) 2mT and (b) PREC and for classifications comprising 9 (upper panel), 18 (middle panel) and 27 (lower panel) types. Note that not all methods are represented in all categories of type numbers. Colours denote method groups. The explained variances have been calculated for each month separately. The total number of cases which corresponds to a y-axis value of 1.0 is 144 (12 months by 12 domains).

4.2.3.12 Influence of the size of the classification domain on CTC performance

Results presented so far have shown that apart from methodological differences among varying classification concepts the relationship between circulation types and surface climate parameters depends on a number of “boundary conditions” that are independent of the respectively applied classification method (e.g. number of designated circulation types, number and type of input variables, sequential classification, temporal resolution). In this section the of varying domain size that is used for classification on the relationship between circulation types and surface climate parameters is investigated on the basis of a small sample of CTCs from the COST733CAT database.

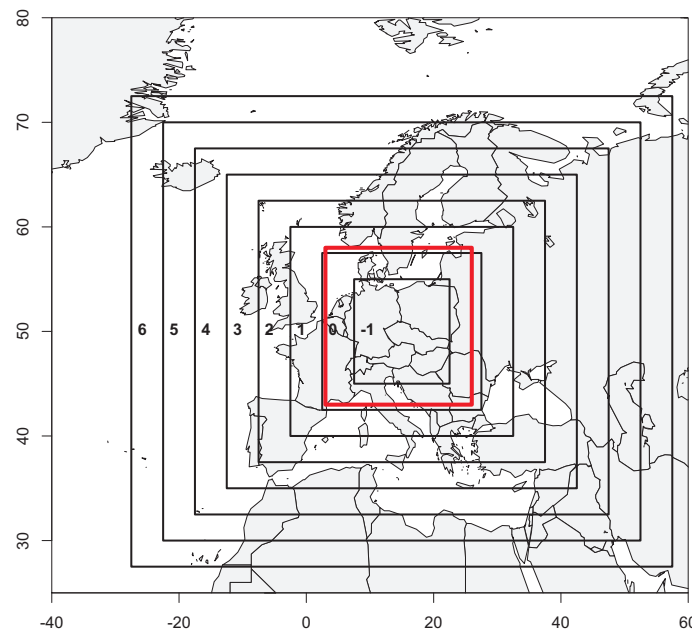


Figure 4.30: Definition of classification domains of varying size (–1 to 6), illustrated for one selected “original” COST733 domain (domain 7). Sizes of “flexible” domains increase from –1 to 6, with size 0 representing the original domain size (red rectangle).

The 5 selected circulation type classifications, each of them representative for a general methodological approach, are:

- CAP: Cluster Analysis of Principal components
- GWT: Threshold based Grosswetter-types or prototype classification
- LND: Correlation based Lund classification
- SAN: Simulated annealing and diversified randomization clustering
- TPC: mode principal component analysis.

These classifications have been applied iteratively to domains of differing size, each of them centered over a specific “target domain” of fixed size within the North-Atlantic European region (see Fig. 4.30 for an example of the definition of such “flexible” domains).

Based on the resulting circulation type catalogues and surface climate data for the respective “target domains” (daily gridded ERA40-reanalysis data and daily station data for temperature and precipitation respectively) the above introduced evaluation metrics have been calculated in order to quantify the discriminative power of each classification depending on the size of the domain used for classification. In the following only results for the Central European domain 7 using EV as evaluation metric are presented for 2mT and PREC in winter (Fig. 4.31) and summer (Fig. 4.32).

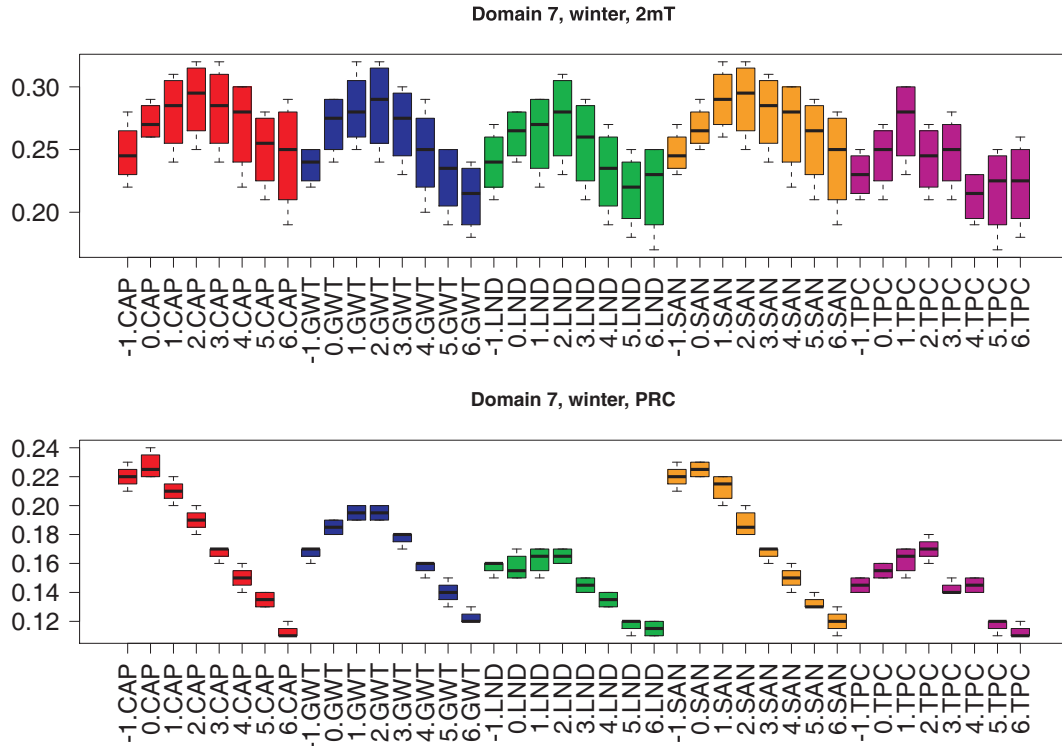


Figure 4.31: Explained variation (EV in %) estimated for five selected classifications for (top) 2mT and (bottom) PREC in winter (DJF). Classifications have been performed on the basis of size modifications of original COST733 domain 7. Evaluations have been performed in all cases on the basis of gridded ERA40 reanalysis data covering the respective “original” domain.

For both variables – 2mT and PREC – a marked dependency of evaluation results on the size of the domain can be stated. For 2mT domain sizes 2 and 1 appear to be the most appropriate domains whereas for PREC best performance is mainly reached with even smaller domain sizes. Comparing results for winter and summer it turns out that highest EV values in summer in most cases are connected to smaller domain sizes than in winter. This finding again points to the greater influence of small scale circulation features on surface climate conditions during summer.

However, the relations between domain size and the performance of classifications vary distinctly among classification methods and as well among climate variables and regions (not shown). Thus, at this stage it is not possible to define a generally optimum domain size for circulation type classification.

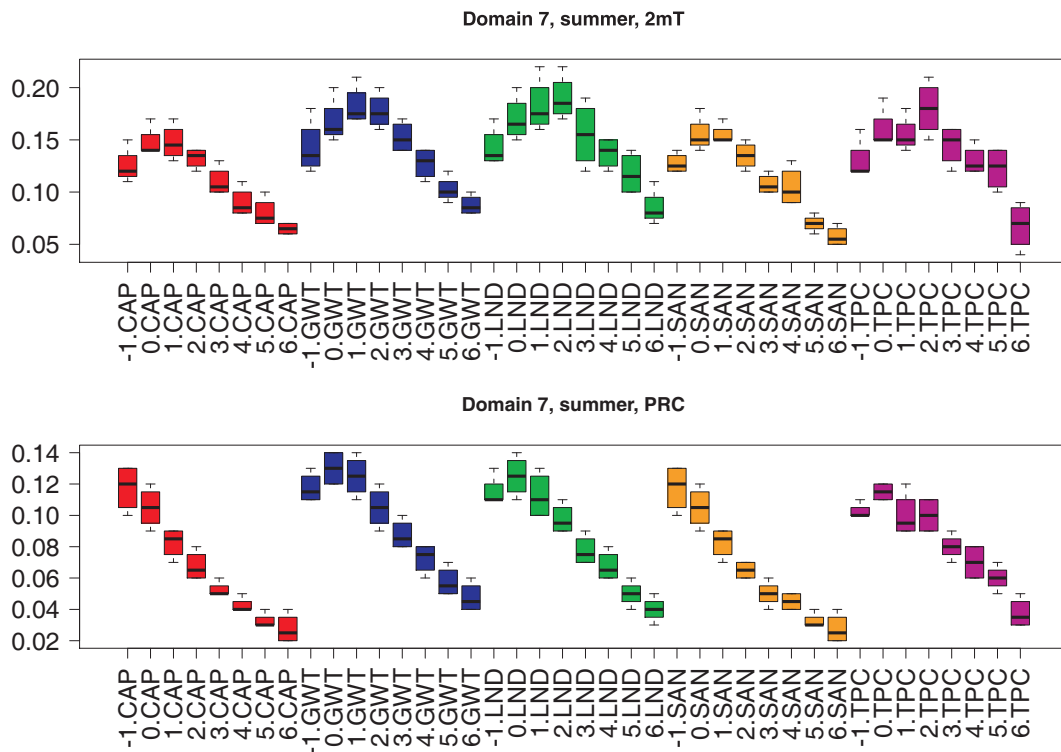


Figure 4.32: As in Fig. 4.31 but for summer (JJA)

4.2.4 Summary and Conclusions

The main findings from the evaluation and comparison studies on the basis of the comprehensive COST733CAT database of circulation type classifications presented in this contribution may be summarized as follows.

Results of the determination of similarity indices between circulation type classifications show that conformities in the methodological approach of different classifications are not necessarily reflected by accordingly pronounced higher similarity levels (only for the OPT group of methods slightly enhanced similarities among members of this group can be stated).

For the evaluation and comparison of circulation type classifications it has turned out that the results of all analyses show a distinct sensitivity to the number of circulation types. Thus it can be concluded that comparison studies that are intended to compare methodological approaches should focus on CTCs comprising approximately the same number of circulation types. Only then results of evaluations and comparisons reflect differences between classification methods and not merely differences due to varying numbers of circulation types.

Beside distinct differences in performance of classifications between spatial domains, seasons and climatic target variables some general characteristics of the performance of classifications can be stated. Averaged over the whole ensemble of circulation classifications generally higher performance is reached for winter months, for smaller spatial domains located more to the west, and for MSLP compared to 2mT and PREC. Higher performance for MSLP is undoubtedly due to the fact that all classifications use this variable (amongst others) for classification. Systematic differences in general performance levels between seasons and spatial domains on the other hand can be explained

by respective spatio-temporal variations in the intensity of the links between large-scale circulation and surface climate.

Analyses reveal a general concordance between performance for MSLP and climatic target variables 2mT and PREC. However this relationship varies distinctly between seasons and spatial domains. Thus it can be concluded that high performance levels for one target variable are not necessarily connected with comparable high performance for the other target variables.

Comparisons of different groups of basic classification methods reveal that there is no overall best basic method. However it can be stated that CTCs utilizing optimization algorithms reach highest performance for MSLP in most cases. However this superior performance for MSLP is not systematically related to comparable high performance levels for associated climate variables for which in many cases other method groups reach higher skill (PCA and LEAD for 2mT, THRES for PREC).

Variations in performance of classifications can partly be attributed to corresponding modifications of the classification settings. The utilization of 4-day sequences instead of single days leads to higher performance levels for 2mT, especially in winter and autumn. For MSLP and PREC on the other hand sequencing reduces performance. Applying classifications on seasonal subsets instead whole year samples leads to an improvement in performance only when comparing the seasonal 9 type per season classifications with classifications comprising only 9 types for the whole year. Comparison with classifications producing 27 types for the whole year on the other hand reveal lower performance for the seasonal classifications. Finally the inclusion of additional input variables into classifications leads to better evaluation results compared to classifications utilizing only MSLP mainly for 2mT (1000/500 hPa thickness in winter and autumn; 500 hPa height, 500 hPa vorticity and 1000/500 hPa thickness in summer and spring). Concerning PREC mainly the additional use of 500 hPa vorticity results in higher performance levels.

The comparison of individual classifications confirms the main findings stated above. No single overall best classification can be deduced from the evaluation results achieved for spatial domains, seasons and with respect to different target variables. Moreover it becomes evident that distinct variations in skill exist not only among classifications from different groups of basic methods but as well between classifications from the same method group. However although it is not reasonable to appoint single best classifications in a generally binding sense such comparisons of individual classifications may serve as a guide for finding the most appropriate classification approach for a specific domain, season and target variable.

Beside variations in performance among spatial domains performance variations have to be considered within spatial domains as well. From evaluation studies performed on the basis of individual gridpoint data it can be concluded that in most cases only minor variations in performance for MSLP appear within individual spatial domains. For 2mT and PREC on the other hand classifications exhibit distinct spatial variations in performance and different classifications reach highest performance in different regions within domains.

Deliberate classifications from the COST733CAT-database have been compared pseudo random RAC classifications. The main results from these comparisons is that pseudo random classifications in many cases reach performance levels as high or even higher than many deliberate classification methods. In general comparing classifications with randomly generated partitions can be seen as a promising additional approach for evaluation the performance of circulation type classifications.

Analyses of the relevance of the size of the spatial domain used for classification revealed that variations in domain size are related to distinct differences in CTC performance with better performance mainly related to smaller domains. However it is not yet possible to deduce general rules on the optimum size of the domain on the basis of the few case studies carried through within COST733.

Based on the presented results of basic evaluation studies performed within COST733 it has been possible to provide recommendations for the application (WG4 of the COST733 Action) and the development (WG2 of the COST733 Action) of CTCs:

CTCs using optimization algorithms (OPT) should preferably be used for analyses that strongly rely on the availability of well defined circulation patterns (e.g. long-term frequency variations of circulation types) as these classification methods provide circulation types with highest/lowest separability/within-type variability.

For relating circulation types to surface climate variables (e.g. for statistical down-scaling purposes) the use of LEAD, PCA based or threshold based CTCs – in some cases – appears to be more appropriate.

During the course of the COST733 Action several results from the basic evaluation studies have been communicated to WG2 and have led to several modifications of classification approaches included in the most recent version of the COST733CAT-database, e.g. the inclusion of the vorticity parameter as additional input variable for classification ([BECK and PHILIPP, 2010](#)).

4.3 Assessing synoptic-climatological applicability of circulation classifications by the Kolmogorov-Smirnov test

By Radan Huth

4.3.1 Background and goal

In this section we discuss the synoptic-climatological applicability of circulation classifications produced within the COST733 Action. Under the ‘synoptic-climatological applicability’ we understand the ability of a classification to stratify the values of a surface climate variable. We apply a methodology for assessing the synoptic-climatological applicability, based on the Kolmogorov-Smirnov test of homogeneity of two distribution functions, to daily maximum and minimum temperatures and precipitation totals at the network of stations across Europe. This is just one of several possible criteria for assessing the synoptic-climatological applicability.

In the analysis, we concentrate on answering the following questions: (a) Is there a clear ranking of methods? Are there some methods that can be seen as superior/inferior to others? Is there any optimum method? (b) Is there a systematic effect of the number of types in classifications, sequencing, adding more variables to SLP in classification, seasonality of the definition of classifications? (c) Are there systematic differences among variables in the answer to the previous questions? (d) Are the results sensitive to the size of the domain, i.e., are there differences between the large domain (D00) and the other smaller domains? (e) Are the results robust across all smaller domains or are there geographical or random variations in them?

4.3.2 Methodology

We employ the procedure introduced and described in [HUTH \(2010\)](#). For each circulation type in each classification and at each station, a conditional empirical probability distribution function (pdf) of a given element (maximum or minimum temperature) is constructed. It is then compared with the pdf at that station for the rest of data, i.e., for all days except those classified with the given type. This assures that the two samples for which distribution functions are compared are independent, which would not be the case if we conducted the comparison against the distribution of all data. The comparison is conducted using the two-sample Kolmogorov-Smirnov (K-S) test. The rejection of the test indicates that temperature values under the particular type are well separated from the values in the rest of data; the acceptance of the test tells us that temperature under the particular type does not significantly differ from the rest of data. It is important to note that the K-S test reflects a whole pdf, not only the mean value; thanks to it, a type connected with a narrow temperature distribution around the long-term mean may be seen as having temperature different from overall conditions, which would not be possible if e.g. the standard t-test for the equality of means were employed. A more detailed description of the test, including the formula for the test statistic and critical value, can be found in many statistical textbooks; see e.g. [WILKS \(1995\)](#).

The K-S statistics can be mapped: such maps can be drawn for each type from any classification. The maps can disclose areas where temperature or precipitation under

..... 4.3 Applicability of classifications assessed by K-S Test

the particular type is significantly different from the rest of data, that is, where the type is accompanied by specific temperature conditions (for an example, see Sect. 4.3.4.1). Then the numbers of rejections of the K-S test are counted over individual types for each classification at each station; we choose the significance level of 5%. The larger the number of rejections, the better the stratification of surface temperature by the particular classification at a given station. The percentage of rejections can be calculated at each station and also be mapped, thereby disclosing areas where the particular classification is suitable to synoptic-climatological studies of temperature (Sect. 4.3.4.2). The classifications are then ranked at each station by the percentage of the K-S test rejections. The ranks can be averaged over stations, thus providing an area mean rank for each classification. Finally, the classifications are ranked by the area mean rank (Sect. 4.3.4.3).

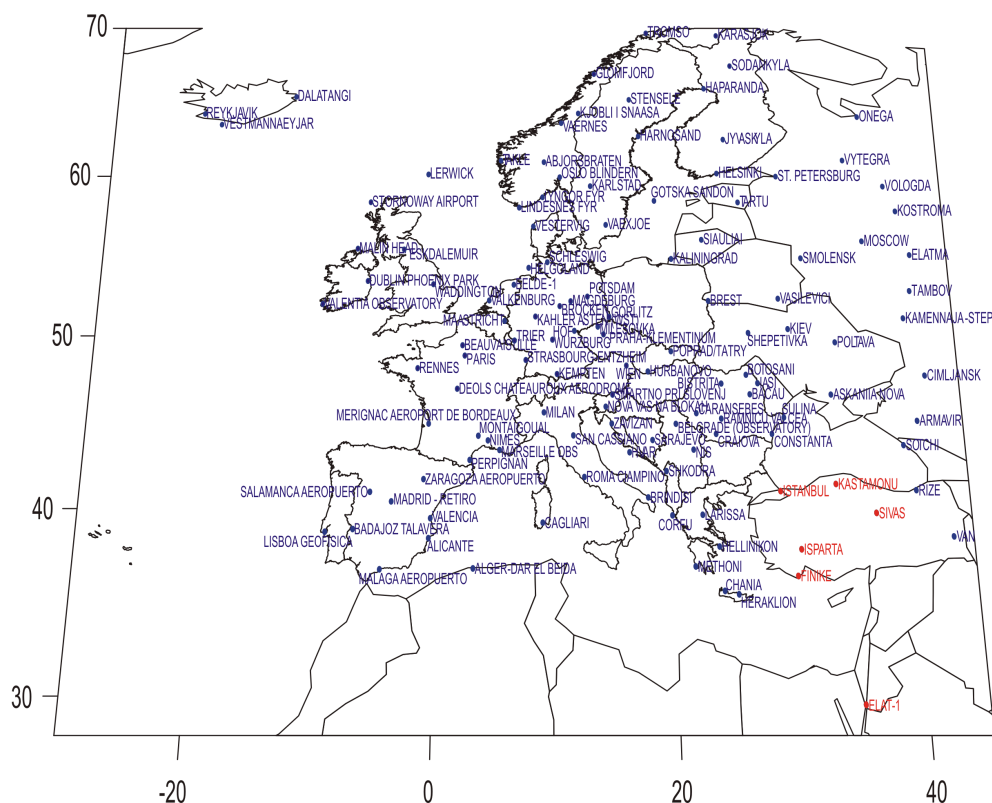
The presence of very small classes (groups) affects results of the K-S test negatively; the inferior ranking of such a classification is thus a reflection of the presence of a very small class(es) rather than a bad performance of the method. We therefore omit classes with 10 and fewer days from the analysis.

4.3.3 Data

Daily surface maximum and minimum temperatures at 126 European stations are taken from the database of the European Climate Assessment (ECA) project (KLEIN TANK *et al.*, 2002, updated). Their location is shown in Fig. 4.33. For evaluation of each domain, only stations within that domain are used. The numbers of stations in each domain are given in Tab. 4.1. Analyzed are winter (December to February) and summer (June to August) seasons in the period 1961–2000. The reason for choosing this period, which is five years shorter than the period for which the classification database has been produced, is the availability of temperature and precipitation data, which becomes considerably worse outside this period.

Table 4.1: Numbers of stations in individual domains. In parenthesis are the numbers of stations with precipitation data if different from the total number of stations. Maximum and minimum temperature are available at all stations.

<i>Domain number</i>	<i>Number of stations</i>
00	125 (120)
01	4
02	16
03	12
04	18
05	22
06	25
07	42
08	25 (24)
09	15
10	33 (32)
11	12 (6)



4.3.4 Results obtained on older versions of the databases

As an example, Fig. 4.34 displays maps of the acceptance or rejection of the K-S test for maximum temperature in winter for a selection of Hess and Brezowsky (H-B) subjective circulation types. West cyclonic type (WZ) results in maximum temperature well separated from the overall conditions over almost whole Europe except two stations in the interior of Scandinavia. This is in contrast with three types with a fairly close configuration, west anticyclonic (WA), west angular (WW), and northwest cyclonic (NWZ), which

..... 4.3 Applicability of classifications assessed by K-S Test

do not discriminate temperature under larger parts of Europe. The north anticyclonic type with Icelandic high (HNA) is an example of a type with a good determination of temperature in central Europe and little ability to determine temperature at the southern, northwestern, and northern edges of Europe. On the other hand, the Western European trough (TRW) discriminates temperature at the western and southeastern edges of Europe, but not over its central part, for which the H-B classification was designed. The differences among the types stem not only from their physical properties, but also from their size: the more frequent the type, the higher chance that the K-S test rejects the hypothesis of the equality of pdfs. Note that regions with the acceptance/rejection of the K-S test for the individual types are geographically coherent, which indicates that results do reflect physical and meteorological properties of the types.

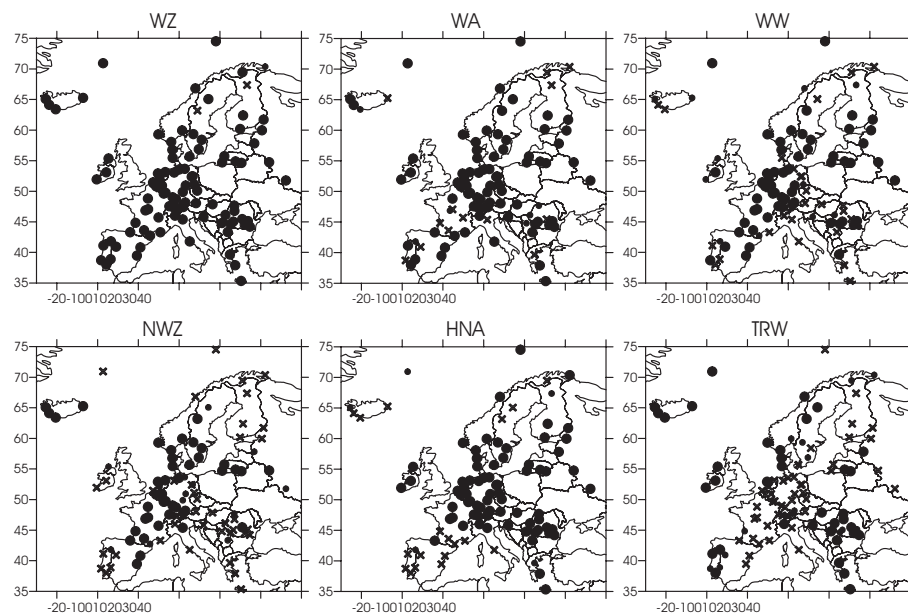


Figure 4.34: Acceptance/rejection of the K-S test for selected H-B types (identified at the top of panels) and maximum temperature in winter: acceptance at the 5% significance level (no difference between the conditional and overall pdf) is denoted by a cross, rejection at the 5% level but acceptance at the 1% level (small significant difference between the conditional and overall pdf) is denoted by a small circle, rejection at the 1% level (large significant difference between the conditional and overall pdf) is denoted by a large circle.

4.3.4.2 Spatial structure of synoptic-climatological applicability for selected classifications

Results of K-S tests for individual H-B types, discussed above, are summarized into one map in the top left panel of Fig. 4.35. We arbitrarily set the level of a ‘good stratification’ to be 70% of all types being distinguishable in their maximum temperature distribution from the rest of data. The stations where fewer types yield temperature pdf different from the rest of data are denoted by crosses, while squares and circles denote a significant difference for more than 70% of types, with larger symbols indicating a better stratification. The H-B classification provides a relatively good stratification over the majority of Europe, with the exception of its northernmost and southwesternmost

parts, a few stations in the Balkans and two stations south of the Alps. Fig. 4.34 displays spatial patterns of synoptic-climatological applicability for several other classifications. Another subjective classification, the Hungarian catalogue after Péczy, does also a good job in stratifying winter maximum temperature over large parts of Europe, from Scandinavia through France and Germany, to the eastern Mediterranean. The Swiss subjective classification after Schüepp, which is rather local in its definition, with no intention to characterize weather conditions outside Switzerland, and also somewhat discriminated by a very high number of types, 40, is capable of stratifying temperature over a wider area of central to western Europe, reaching to Ireland and central Scandinavia, and even to selected stations in Italy and Greece.

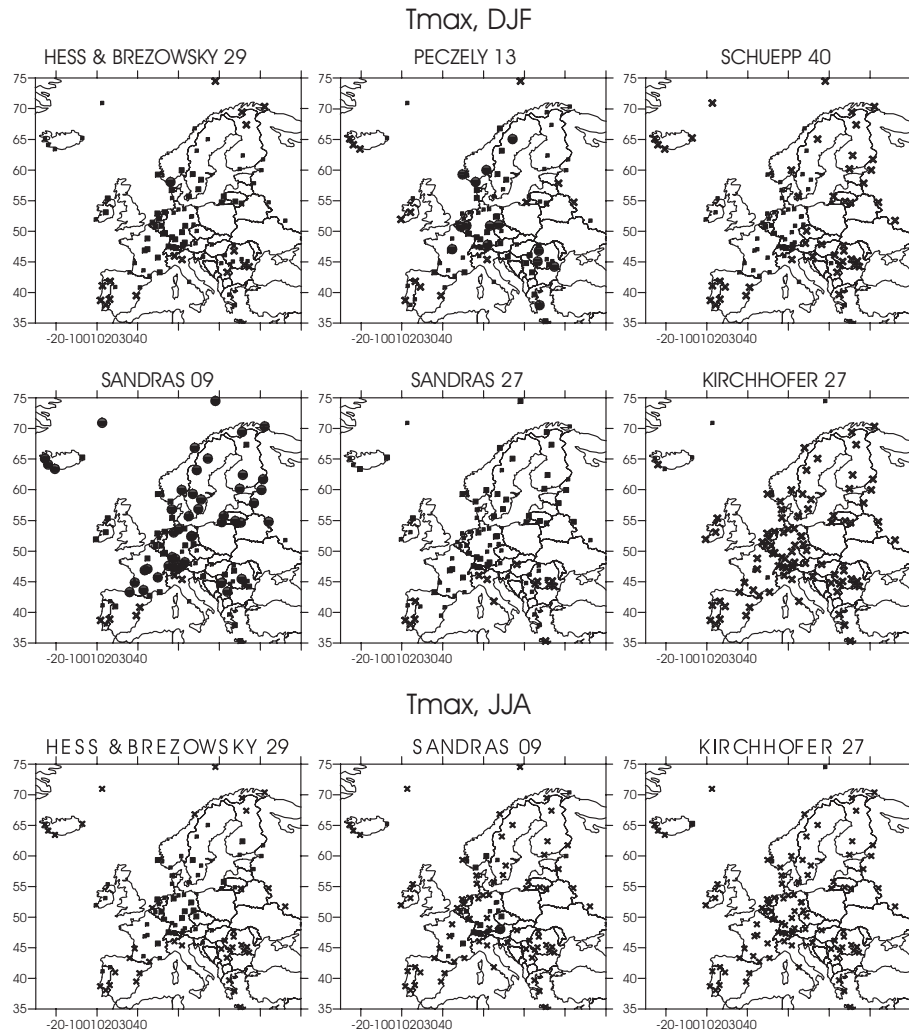


Figure 4.35: Percentage of the K-S test rejections (at the 5% significance level) for maximum temperature in winter (upper two rows) and summer (bottom row) for a selection of classifications from v1.2 of the database, identified at the top of panels, together with their number of types. The objective classifications are defined over the large European domain (00). Large circle: rejection of K-S test for all types; medium square: rejection for more than 85% of types; small square: rejection for 70 to 85% of types; cross: rejection for less than 70% of types.

The three objective classifications, all developed for the whole European domain (00), exhibit behaviour different from each other. The sequential SANDRA cluster analysis

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(SANDRAS) yields better stratification for 9 than for 27 types. Nevertheless, even SANDRAS with 27 types yields K-S test rejections for more than 70% of types over most of Europe, the only areas where a good stratification is not achieved being parts of southern Europe. In contrast to SANDRAS, the Kirchhofer classification (KH), which has 27 types as well, yields a good stratification almost nowhere. On the few examples shown, one can see a wide diversity of circulation classification methods in their ability to stratify maximum temperature in winter. In spite of this, several common features of most classifications, including the subjective ones and the objective ones defined on the whole European domain (00), can be found. The stratification by most classifications tends to be better in the centre of the domain than at its edges, which could be expected; nevertheless, there are notable exceptions. For example, many classifications provide good stratification over fairly remote Iceland; on the other hand, the stratification tends to be particularly inferior over western Iberian Peninsula, the Balkans, northern Norway, and along the eastern border of the domain (western Russia). Results for minimum temperature are similar.

In summer, the number of rejected K-S tests tend to be lower, which is a consequence of a weaker effect circulation has on surface temperature in summer than in winter. Three examples are shown in the bottom row of Fig. 4.35.

4.3.4.3 Dependence on the number of types

The varied ability of classifications to stratify surface maximum temperature prompts an attempt to rank the classifications. At every single station, the classifications are ranked by the percentage of rejected K-S tests (at the 5% significance level), that is, by the percentage of types well separated in terms of temperature. The higher the percentage, the better the stratification, and the lower the rank of a classification. The ranks obtained this way are then averaged over stations and the area mean rank is calculated, which provides the final ranking of classifications.

As already discussed above, results depend on the number of classes. This dependence follows from that the lower number of types implies their larger sizes, smaller differences between pdfs are therefore needed to achieve statistical significance, which leads to more rejections of K-S tests, and therefore to a better stratification. The dependence of the stratification ability, quantified by the rank of a classification, on the number of classes, is illustrated in Fig. 4.36. Clearly, the best stratifying classifications with higher numbers of types (about 18 and about 27) are shifted to higher ranks relative to the best classifications with the low number of types (about 9). This shift is larger for classifications defined on a small domain (central Europe, 07), and is considerably larger in winter than in summer when it is barely visible.

4.3.5 Results obtained for v2.0 of the COST733 database

In this section we present results for the most recent version of the COST733 database and 126 stations. All 423 classifications were ranked for each of the three target variables (maximum temperature, minimum temperature, and precipitation) in each of the 12 domains. All analyses and results presented in this section are based on these rankings. However, only a subset of all classifications available enters the analyses. We omit four groups of classifications from further consideration: (i) subjective classifications and their objectivized versions (GWL, OGW, PEC, PER, SUE, ZMG), (ii) the original

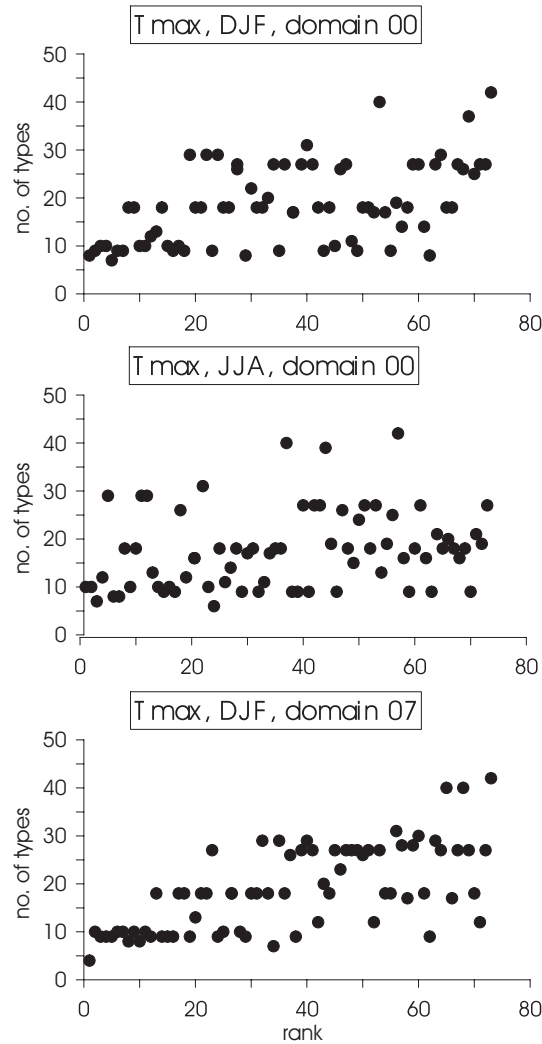


Figure 4.36: Relationship between the rank of classifications from v1.2 of the database and the number of types in them for maximum temperature. Top: winter, domain 00 (whole Europe); middle: summer, domain 00; bottom: winter, domain 07 (central Europe).

classifications provided by their authors, that is, those not calculated by the COST733 software (i.e., those classifications denoted by ‘o’ at the fourth place in their name), (iii) the WLK method, and (iv) the SOM method. Respective reasons for omitting them are as follows: (i) Subjective classifications have just one realization (a single number of types; except for GWL), which precludes them from comparisons as to the number of types, sequencing, additional variables, seasonality of the definition, etc. (ii) The original classifications are reproduced by those produced by the COST733 software to a different degree of similarity, the reasons for differences being several times unclear; also, the original classifications cannot be used for assessing sensitivity to sequencing, additional variables, etc. In many cases, the original classifications and those produced by the COST733 software are very similar, which would bring an undesirable redundancy into the analysis. (iii) The WLK method uses, as the only method in the database, many input variables for its definition even in its basic version; this precludes a fair comparison with all other methods, which are based on SLP only in their basic version.

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(iv) The SOM method yields results identical to SAN, and is available for 9 types only. So in result, 367 classifications enter the ‘competition’. They include (i) 4 methods with three realizations (for three different numbers of types; GWT, JCT, LIT, KIR), (ii) 6 methods with 30 realizations (for all possible combinations of numbers of types, no and 4-day sequencing, and four additional sets of variables; KRZ, PXE, PCT, PTT, LND, PXK), and (iii) 5 methods with 35 realizations (all as in group (ii) plus seasonal definition for all sets of additional variables but with a single number of types and without sequencing; ERP, CKM, CAP, SAN, RAC). It is worth stressing again that the ranks are attributed to all the 423 classifications, that is, the ranks of the classifications range from 1 (best) to 423 (worst), not to 367.

4.3.5.1 Ranking of methods

In this subsection, the comparison is carried out for the ‘basic’ versions of the classification methods, i.e., those where SLP is the only input variable, without sequencing, and with the annual, not seasonal, definition of types. The main reason is to allow the methods for which no sequencing and/or no additional input variables have been employed to also enter the competition. Three variants of each method, differing in the number of types (≈ 9 , ≈ 18 , ≈ 27) are available. The ranking of the methods is obtained by averaging the ranks over these three variants, and ranking the average.

It should be noticed, however, that real numbers of types in some classifications differ from the ‘theoretical’ ones. The reason is that in a particular season, not all types may occur in reality because of a pronounced seasonality of occurrence of individual types, or they occur too infrequently so that they are omitted from the analyses (the threshold used is 10 days in the whole 40-year period). As a consequence, even a comparison among classifications with the same theoretical number of types (≈ 9 , ≈ 18 , ≈ 27) does not ensure that real numbers of types are the same; and because of the property of the K-S criterion to favour classifications with lower numbers of types, the evaluation may be biased towards classification methods that produce fewer types in the analyzed seasons (or, in other words, producing classifications with strong seasonality) being evaluated as too good.

Different classifications (and classification methods) differ in the degree of their seasonality; this issue is more discussed in the part of this report related to WG4. Here, as an illustration, Tabs. 4.2 and 4.3 display the real number of types with the occurrence frequency of more than 10 in the analysis period, for 15 examined methods, with ≈ 27 theoretical types, SLP as the only input variable, no sequencing, and annual definition, both for winter and summer. One can see that (i) several methods are prone to producing fairly low numbers of types (e.g., PTT, PCT, PXE, PXK, ERP), that is, either exhibit strong seasonality or produce very small or even empty types; (ii) the tendency to fewer really occurring types is much stronger in summer; and (iii) the tendency to fewer really occurring types is particularly strong in domain D11 (eastern Mediterranean).

Table 4.2: Numbers of types with population of at least ten days for classifications with SLP as the only input field, 27 theoretical types, no sequencing, and annual definition. Winter.

<i>Method</i>	<i>D00</i>	<i>D01</i>	<i>D02</i>	<i>D03</i>	<i>D04</i>	<i>D05</i>	<i>D06</i>	<i>D07</i>	<i>D08</i>	<i>D09</i>	<i>D10</i>	<i>D11</i>
GWT	25	26	26	26	26	26	26	26	26	26	26	26
JCT	26	27	20	26	26	27	20	26	27	27	26	21
LIT	27	27	27	27	27	27	27	27	27	27	27	27
KRZ	27	27	27	27	27	27	27	27	27	27	27	24
PXE	18	11	15	14	18	15	15	16	13	20	16	21
PCT	23	24	22	19	20	18	18	17	16	18	18	12
PTT	11	8	8	11	10	6	6	8	9	8	7	7
LND	24	26	26	26	27	27	26	27	26	25	26	26
KIR	27	27	27	27	27	27	27	27	27	27	27	27
ERP	16	20	18	18	22	20	19	20	20	20	20	16
CKM	27	27	27	25	27	25	22	26	26	27	25	23
CAP	27	27	27	27	27	27	27	27	27	27	27	23
PXK	17	11	14	14	18	14	15	16	13	19	15	22
SAN	26	27	27	27	27	27	27	27	27	27	27	22
RAC	26	27	26	27	27	27	27	27	27	26	26	23

Table 4.3: As in Tab. 4.2 but for summer.

<i>Method</i>	<i>D00</i>	<i>D01</i>	<i>D02</i>	<i>D03</i>	<i>D04</i>	<i>D05</i>	<i>D06</i>	<i>D07</i>	<i>D08</i>	<i>D09</i>	<i>D10</i>	<i>D11</i>
GWT	21	26	26	26	26	26	26	26	26	25	26	10
JCT	27	27	25	27	27	26	10	27	26	20	12	8
LIT	27	27	27	27	27	27	27	27	27	27	27	27
KRZ	25	27	27	27	27	27	26	27	27	26	26	20
PXE	18	11	16	14	18	15	15	16	13	20	16	17
PCT	10	24	17	13	21	13	14	13	9	9	11	7
PTT	8	11	14	11	8	12	11	11	13	6	8	3
LND	22	27	27	27	27	27	26	27	26	20	25	8
KIR	26	27	27	27	27	27	27	27	27	24	25	18
ERP	11	12	8	11	14	15	10	11	11	15	13	12
CKM	12	16	15	13	19	14	10	12	13	12	11	7
CAP	14	22	20	21	23	22	22	19	17	15	16	10
PXK	19	11	16	14	18	15	15	16	13	18	16	15
SAN	13	21	22	20	23	20	21	19	18	15	15	9
RAC	14	22	23	21	22	20	21	18	15	12	16	13

Winter

For each domain, the ranks for maximum temperature, minimum temperature, and precipitation may be plotted in one graph, as is exemplified in Fig. 4.37 for four selected domains: D00, D03, D07, and D09. One can see large differences among methods in their performance (ranking); however, the rankings of individual methods are not the same in all domains, but differ considerably. There are also marked differences between target variables for the same method and domain.

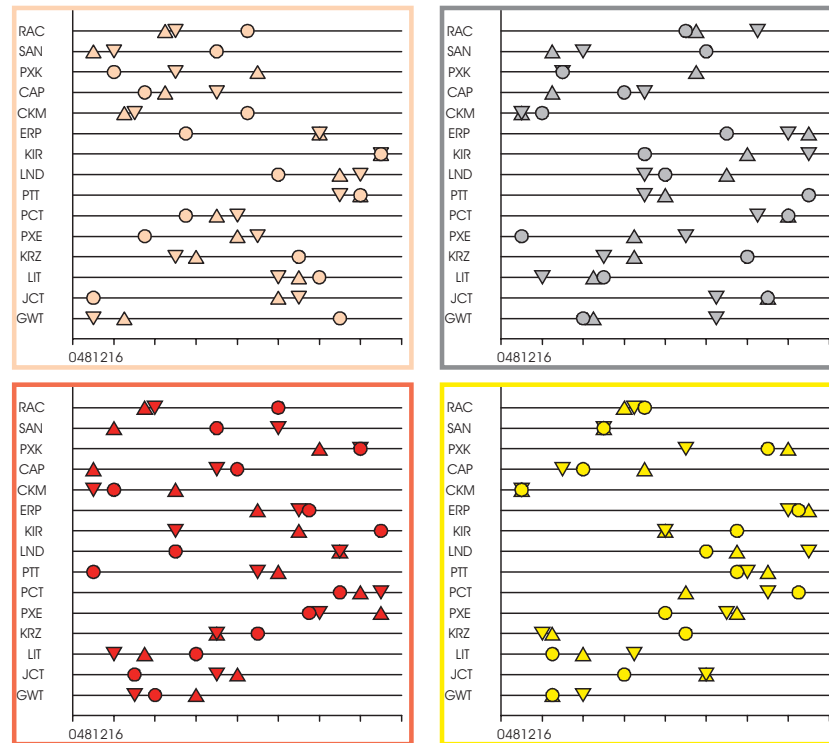


Figure 4.37: Ranking of classification methods in domains D00 (top left), D03 (top right), D07 (bottom right), and D09 (bottom left) for maximum temperature (upward triangle), minimum temperature (downward triangle), and precipitation (circle). All for winter.

The information from all domains can be summarized by putting the graphs from Fig. 4.37 for all the domains together, resulting in an ‘abacus’ diagram in Fig. 4.38 where individual domains are distinguished by colours. Although most classification methods spread the whole range from the very good ones (low ranks) through moderate up to inferior ones (high ranks), there are a couple of methods that can be identified as generally superior, while several others can be considered generally inferior. The methods that generally perform well (and almost never badly) include GWT, LIT, CKM, CAP, and SAN. At the opposite edge we find the generally badly performing methods, which almost never perform very well: PXE, PCT, LND, ERP, and PXK.

Whether there is a systematic difference in performance of the methods between target variables, can be deduced from Fig. 4.39 where ranks from Fig. 4.38 are averaged over the domains. This way we get a mean performance of each method for individual target climatic variables, irrespective of geographical location. One can see that for all methods, the ranks for maximum and minimum temperature are close to each other and that there do not seem to be any systematic differences in the performance of classification

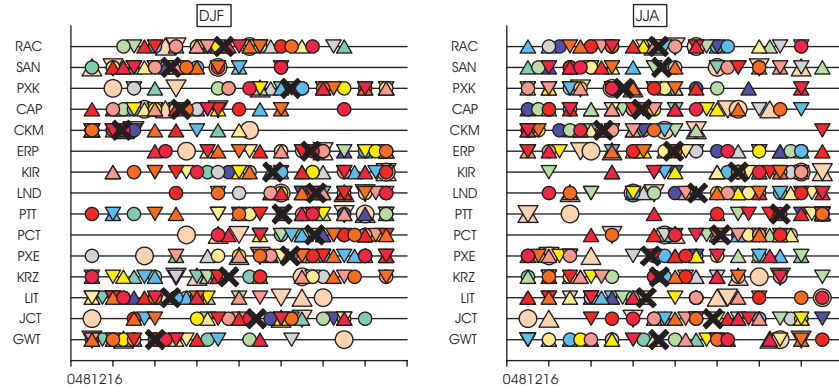


Figure 4.38: Ranking of classification methods in all domains. Symbols correspond to target variables as in Fig. 4.37; colours refer to domains: D00 – brown, D01 – turquoise, D02 – blue, D03 – grey, D04 – green, D05 – pale blue, D06 – olive, D07 – yellow, D08 – pink, D09 – red, D10 – orange, D11 – neon red. Symbols for D00 (large domain) are larger. Crosses indicate mean ranks (over 12 domains and 3 target variables) for each method. Note that there are many overlaps of symbols, so not all individual symbols can be seen. Left: winter; right: summer.

methods between the two temperature variables. On the other hand, the performance for precipitation is somewhat different for several methods. Thus PXE and PXX methods tend to perform relatively better for precipitation than for temperature, while the opposite is true for KRZ. This is interesting because the similar method, GWT, which differs only in the way the large-scale flow configuration, with which the daily patterns are correlated, are determined (a priori for GWT versus by PCA for KRZ), does not display such a behaviour.

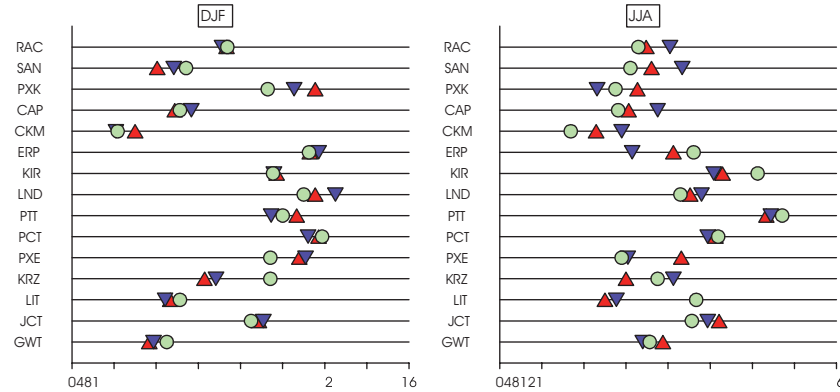


Figure 4.39: Ranks of classification methods averaged over all the 12 domains for maximum temperature (red, upward triangle), minimum temperature (blue, downward triangle), and precipitation (green, circle). Left: winter; right: summer.

Fig. 4.40 displays rankings from Fig. 4.38 for the individual domains averaged over the three target variables. There is no apparent geographical dependence of rankings (e.g., north vs. south, west vs. east) for any method. However, several methods suggest they are sensitive to the size of the domain: they differ in their performance between the large domain (D00) and the smaller domains. Most striking is this difference for LIT, which is among the leading methods for small domains, but performs much worse on the large domain. A similar effect, though weaker, is observed for KIR. Also CKM performs

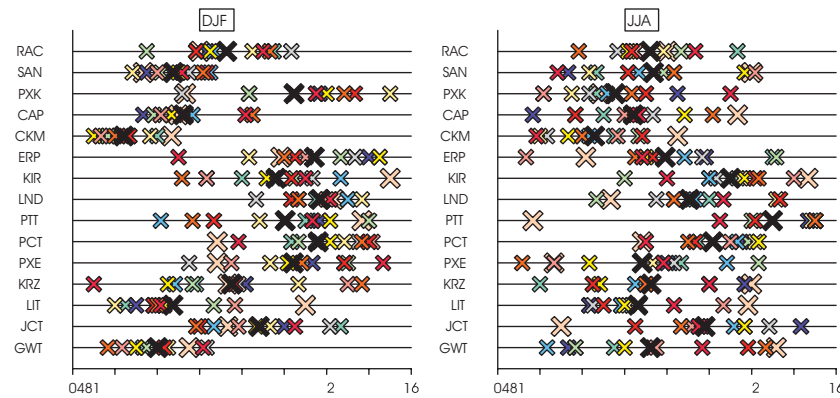


Figure 4.40: Ranks of classification methods averaged over three target variables for individual domains (colour key same as in Fig. 4.38). Large black crosses also as in Fig. 4.38. Left: winter; right: summer.

relatively worse for the large domain; however the distance from the smaller domains is fairly small. The opposite behaviour, i.e., a better performance for the large domain, is seen for PCT, and to a lesser extent also for PXE and PXK.

The varied performance of the methods in different domains and for different target variables suggests that no method can be identified as the generally best (the same holding for the worst) and that a single ranking would have a limited information value. Nevertheless, in the end we provide the final ranking of the methods – if not for anything else, so at least for information or just for fun (especially of their original authors?). Tab. 4.4 contains the ranking of ranks averaged both over domains and target variables (denoted by black crosses in Figs. 4.38 and 4.40). The table also displays another measure of quality of the classifications, namely, the numbers how frequently (out of 36 cases = 12 domains by 3 target variables) the classification method appears among the best or worst three methods. The CKM method is ranked first, so it seems to be the best among all the examined methods; but note that it is not optimum in all cases (see Fig. 4.38), and in particular, does not seem to be well suitable to the large domain. Together with CKM, four other methods may be considered as generally well performing and recommendable: GWT, LIT, SAN, and CAP. They are representatives of two families of methods: cluster analysis (CKM, SAN, CAP) and threshold-based (GWT, LIT). Note that there is no PCA-based nor leader algorithm method among the best performing ones.

Summer

Rankings of all classifications are shown in Fig. 4.38. The spread across the whole range of quality (in terms of the K-S criterion) is even larger than in winter. Only the CKM method seems to concentrate at the ‘good’ end of classifications (with one exception), whereas only PTT, KIR, and to a lesser extent LND concentrate at the ‘bad’ end.

There is a larger spread of performance for target variables, compared to winter (Fig. 4.39); there are marked differences even between maximum and minimum temperature. However, it is hard to draw any conclusions since the pattern seems to be chaotic. Maybe only a worse performance of LIT for precipitation than temperature is worth mentioning.

Table 4.4: Ranking of classification methods

<i>Method</i>	<i>Winter months</i>			<i>Summer months</i>		
	<i>Times among top three</i>	<i>Times among bottom three</i>	<i>Final rank</i>	<i>Times among top three</i>	<i>Times among bottom three</i>	<i>Final rank</i>
GWT	18	1	2	10	8	6
JCT	5	7	8	2	9	12
LIT	13	–	3	7	3	4
KRZ	7	5	7	12	6	8
PXE	2	11	11	13	3	5
PCT	–	17	14	–	9	13
PTT	5	11	10	3	28	15
LND	–	16	15	4	8	11
KIR	3	11	9	1	14	14
ERP	–	16	13	7	8	10
CKM	30	–	1	16	1	1
CAP	10	1	5	10	3	3
PXK	3	13	12	14	2	2
SAN	13	–	4	10	6	9
RAC	3	2	6	6	4	8

Rankings for individual domains (Fig. 4.40) show that GWT, LIT, KIR, CAP, and SAN tend to perform worse over the large domain than over the smaller ones; the opposite holds for JCT, PXE, LND, ERP, as well as PTT. The latter method is, however, a specific case since it is not originally designed to classifications and is known to produce one huge class, accompanied by several classes with a small size, and many classes being empty. Unlike in winter, in summer one can observe some regional dependence of the performance of several methods. Specifically, performance of several methods is better in the southern domains (D09, D10, D11, and to a lesser extent also D08, denoted by reddish colours) (JCT, ERP), while other methods (GWT, KIR, PXK) perform worse in the southern domains. On the other hand, a better performance in the northern domains (D01, D02, D03, D05, blueish and grey colours) is achieved by GWT, whereas JCT, PXE, and ERP tend to perform worse there.

The final ranking of the methods is shown in Tab. 4.4. The differences in performance between methods are smaller than in winter, and only CKM and PXK may be claimed to outperform the rest of the methods. Among the methods on the tail, we can count JCT, PCT, PTT, LND, KIR, and ERP. There are several notable differences from the ranking for winter, which may to some extent be explained by the differences in the real number of types, described above. For example, the ranking of GWT, JCT, KIR, and SAN is much lower (their performance is better) in winter, while the opposite holds for PXE and PXK.

Ranking of methods: Summary

Taking results for both seasons together, we may draw the following conclusions concerning the ranking of methods.

1. The most general, trivial, and not much helpful statement: The synoptic-climatological applicability of classification methods considerably varies among target variables (maximum temperature, minimum temperature, precipitation), across domains, and between seasons.
2. Results are contaminated by unequal numbers of really occurring (enough populated) types. The contamination is stronger in summer than in winter.
3. Nevertheless several well-performing methods can be identified: CKM, CAP, LIT, and GWT.
4. Several methods cannot be recommended from the point of view of their synoptic-climatological applicability (but they of course can have other positive properties): PCT, PTT, LND, KIR, ERP.
5. The performance of methods does not manifest considerable differences among target variables. In other words, none method can be identified as particularly suitable for any target variable. Only LIT in summer seems to be better applicable to temperature than precipitation, but it is questionable whether this fact can be generalized.
6. There are hints of systematic differences in the synoptic-climatological applicability of the methods between the large (D00) and smaller (other) domains: GWT, LIT, KIR, and CKM perform relatively better on smaller domains whereas JCT, PXE, and PCT (and, to some extent also PXK) perform better on the large domain.
7. In summer, there is a tendency for several classifications to display a geographical dependence of their synoptic-climatological applicability: JCT and ERP perform better in the southern domains, while GWT, KIR, and PXK perform worse there; GWT performs better in the northern domains, whereas JCT, PXE, and ERP tend to perform worse there. In winter, no such a regional dependency of performance is noticed.

4.3.5.2 Effect of sequencing

To determine the effect of sequencing, classifications based on 4-days sequences are compared with those without sequencing. For pairs of classifications differing only in sequencing, that have all other attributes (number of types, input variables, seasonality) equal, the effect of sequencing is quantified by subtracting ranks of the two classifications (4-day sequence minus non-sequential). A negative difference indicates a lower rank for the sequential classification, and hence an improvement due to the introduction of sequencing.

Fig. 4.41 shows histograms of these differences for all the three target variables in winter in four selected domains. One can see a shift of the distributions for maximum and minimum temperature towards negative values, indicating that sequencing improves the

synoptic-climatological applicability for temperature. For precipitation, an opposite effect is observed: sequencing deteriorates the stratification of precipitation by circulation classifications.

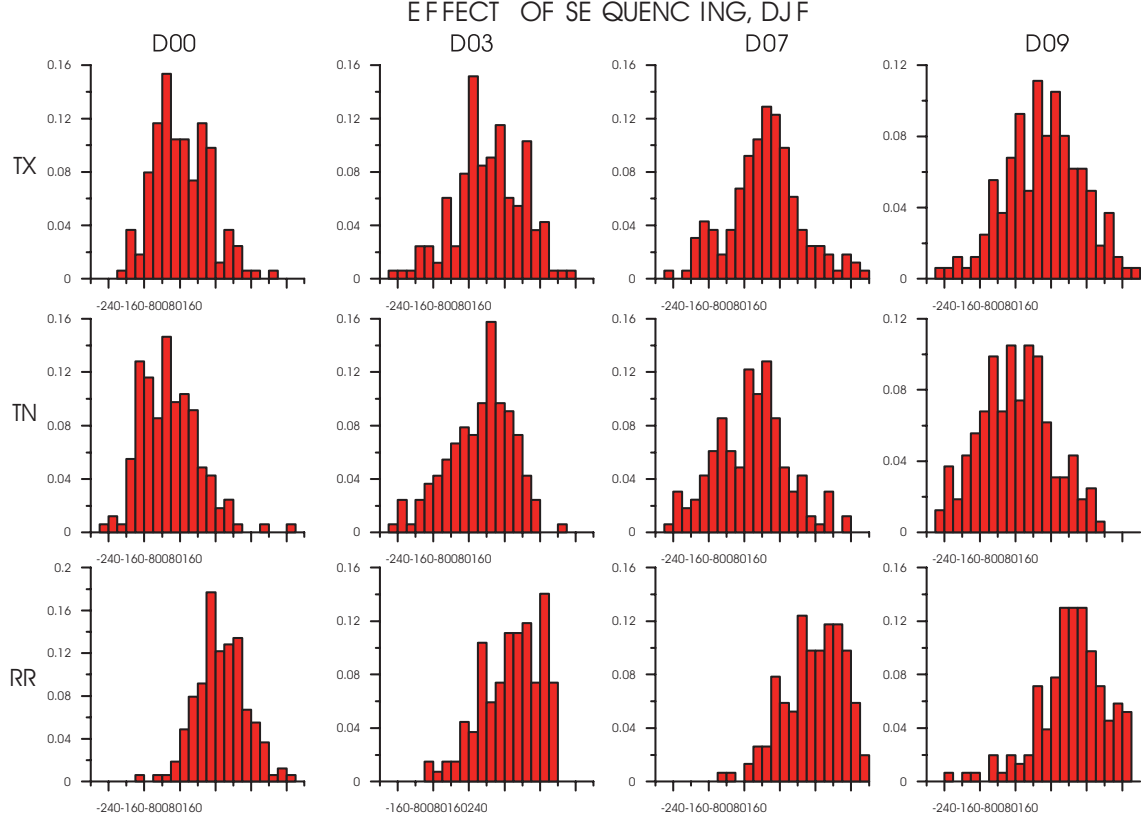


Figure 4.41: Histograms of differences in ranks between classifications of 4-day sequences and non-sequential classifications in winter for domains D00, D03, D07, and D09 (columns) and individual target variables (rows).

Results for all domains and both seasons are summarized in Tab. 4.5, which shows mean differences in ranks between classifications of 4-day sequences and non-sequential ones. Their statistical significance was determined by the standard t-test.

One can see that in winter: (i) Sequencing improves stratification by circulation classifications for temperature (with one exception), but deteriorates it for precipitation. In other words, precipitation is determined mainly by instantaneous circulation conditions, whereas for temperature, circulation on previous days is also important. (ii) The improvement is larger (without any exception) for minimum temperature than for maximum temperature. In other words, circulation on preceding days is more important for determining night-time (minimum) temperature. (iii) The improvement for temperature is largest, and the deterioration for precipitation is smallest, for the large domain. In other words, the circulation features on preceding days relevant for determining temperature are distant from the site where temperature is recorded, and large domain is more likely to comprehend them than the smaller domains.

In summer, the positive effect of sequencing on temperature tends to be weaker. For maximum temperature, the improvements are statistically significant only in two

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Table 4.5: Effect of sequencing. Shown are mean differences in ranks between classifications of 4-day sequences and classifications without sequencing for maximum temperature(TX), minimum temperature (TN), and precipitation (RR) for all the 12 domains. Negative values indicate that sequencing leads to lower ranks, i.e., better stratification of the surface climate element. Negative (positive) values significantly different from zero at the 5% level are printed in bold (italics).

Domain	Winter			Summer		
	TX	TN	RR	TX	TN	RR
00	-72.1	-99.3	<i>+14.1</i>	-75.5	-118.8	<i>+41.4</i>
01	+4.7	-35.2	<i>+83.0</i>	+40.5	-29.0	<i>+107.1</i>
02	-59.0	-75.3	<i>+113.0</i>	-13.8	-77.8	<i>+94.7</i>
03	-35.9	-54.6	<i>+121.7</i>	+2.3	-9.5	<i>+88.8</i>
04	-6.0	-69.4	<i>+94.1</i>	-1.3	-76.5	<i>+90.5</i>
05	-21.2	-40.5	<i>+113.0</i>	+6.9	-40.3	<i>+82.9</i>
06	-33.7	-58.7	<i>+103.3</i>	<i>+30.1</i>	-34.4	<i>+108.0</i>
07	-29.5	-65.1	<i>+88.9</i>	+2.0	-37.4	<i>+102.0</i>
08	-34.4	-59.9	<i>+80.9</i>	+9.1	-9.4	<i>+99.9</i>
09	-11.6	-83.2	<i>+62.7</i>	<i>+22.7</i>	-78.8	<i>+79.3</i>
10	-29.2	-53.8	<i>+72.2</i>	-8.9	-41.1	<i>+92.4</i>
11	-14.3	-37.4	<i>+96.9</i>	<i>+42.2</i>	-30.4	<i>+124.7</i>

domains, whereas deteriorations are much more frequent, some of them being significant. The negative effect of sequencing on precipitation is as strong as in winter. Equally to winter, the improvement for both temperature variables is largest and deterioration for precipitation is smallest for the large domain (D00).

4.3.5.3 Effect of additional variables

To determine the effect of additional input variables, the classifications of SLP plus (an) additional field(s) are compared with those of SLP only. Analogously to the previous section, the effect of adding input variables is quantified by subtracting ranks of each pair of classifications differing only in the input variables, the other attributes (number of types, sequencing, seasonality) being equal. A negative difference indicates a lower rank for the classification with an additional input variable, and hence an improvement due to its addition.

Results are shown in Tabs. 4.6 and 4.7 for winter and summer, respectively. First let us discuss winter. There is a prevalent significant improvement in stratification of both temperature variables due to the addition of 500 hPa heights as well as 1000/500 hPa thickness. Smaller improvements, which fall below the significance level, are found in central Europe and Baltic area (D05, D06, and D07); the British Isles (D04) is the only domain where no significant improvements appear. The addition of heights leads to strongest improvement in southern and southeastern Europe (domains D08 to D11). The response to adding height or thickness is more varied for precipitation; there is a tendency towards significant improvements in southern and southeastern Europe (D08, D10, D11, and to a smaller extent also D09). (*Continued on page 138*)

Table 4.6: Effect of additional input variables, winter. Shown are mean differences in ranks between classifications based on SLP plus the additional variable ('all' meaning 500 hPa height and 1000/500 hPa thickness and 500 hPa vorticity) and classifications based on SLP only. Negative values indicate that additional variable(s) lead(s) to lower ranks, i.e., better stratification of the surface climate element. Otherwise as in Tab. 4.5

<i>Domain</i>	<i>500 hPa height</i>			<i>1000/500 hPa thickness</i>			<i>500 hPa vorticity</i>			<i>All</i>		
	<i>TX</i>	<i>TN</i>	<i>RR</i>	<i>TX</i>	<i>TN</i>	<i>RR</i>	<i>TX</i>	<i>TN</i>	<i>RR</i>	<i>TX</i>	<i>TN</i>	<i>RR</i>
00	-56.0	-58.4	-77.7	-69.5	-73.7	-76.9	+12.3	-14.6	+11.5	-55.3	-56.6	-70.5
01	-31.7	-39.6	-8.4	-34.5	-45.7	+10.8	-2.5	-22.4	+19.1	-48.9	-67.5	+19.2
02	-29.7	-52.3	-16.4	-30.5	-47.5	+17.9	+13.7	+11.3	+2.7	-31.4	-61.7	+9.8
03	-55.0	-60.3	-32.5	-28.3	-28.2	+3.4	+29.2	+34.0	+22.8	-57.9	-62.5	+6.3
04	+8.3	+23.2	-10.4	-7.7	+0.6	-7.7	+25.5	+33.1	-9.4	+18.6	+23.2	+3.5
05	-63.1	-54.1	+4.6	-13.5	-9.6	+28.8	+29.9	+41.2	+47.7	-40.9	-45.3	+48.3
06	-67.8	-66.6	-19.9	-29.2	-34.9	-16.8	+10.0	+30.4	+5.8	-89.5	-72.1	-0.2
07	-15.9	-29.3	-2.3	+3.7	-28.0	+8.1	+34.9	+25.7	+10.5	-53.2	-74.1	-4.2
08	-77.7	-89.4	-30.1	-66.9	-85.8	-23.0	+32.8	+21.1	+22.9	-72.5	-80.4	-13.8
09	-72.0	-34.4	-25.0	-38.1	-10.3	-2.1	-23.9	+28.6	+26.0	-109.6	-57.1	-22.1
10	-76.0	-92.5	-28.1	-39.2	-70.3	-20.5	+27.0	+28.2	+11.5	-90.4	-84.5	-38.5
11	-75.8	-78.1	-82.2	-62.0	-67.1	-61.0	-6.3	+15.1	+13.2	-102.2	-94.0	-63.9

Table 4.7: Effect of additional variables, summer. Otherwise as in Tab. 4.6

Domain	500 hPa height			1000/500 hPa thickness			500 hPa vorticity			All		
	TX	TN	RR	TX	TN	RR	TX	TN	RR	TX	TN	RR
00	-60.5	-78.4	-36.6	-42.4	-54.1	+19.6	-5.5	-0.7	-4.8	-64.2	-91.2	-26.1
01	+31.3	-74.9	+71.5	+61.1	-33.9	+87.4	+10.5	-14.9	+47.0	+38.1	-65.2	+110.4
02	-36.2	-98.2	+86.7	-5.6	-88.9	+92.8	-33.6	-27.4	+1.8	-94.7	-131.9	+94.8
03	-48.1	-107.9	+51.9	-17.2	-85.8	+52.3	-66.2	-50.6	+20.1	-98.9	+146.2	+82.9
04	-19.9	-51.8	+56.5	+29.2	-53.3	+107.0	+15.5	+14.2	+4.2	-24.2	-79.2	+73.4
05	-65.1	-124.6	+67.2	-12.2	-90.9	+79.5	-38.2	-16.9	+12.0	-102.1	-149.4	+92.9
06	-151.0	-183.6	-16.3	-85.5	-148.7	+28.6	-61.8	-29.9	-1.5	-167.1	-185.7	-15.6
07	-119.0	-157.7	-12.8	-96.4	-136.3	+12.2	-44.7	-22.7	-18.5	-131.0	-174.8	-20.9
08	-137.1	-141.4	-16.5	-109.2	-136.9	+14.7	-37.0	-7.5	-7.5	-164.6	-164.6	-41.2
09	-83.3	-126.1	-123.6	-80.3	-132.5	-87.3	-8.3	-0.8	-42.6	-79.8	-117.5	-153.7
10	-162.6	-172.5	-27.5	-148.2	-172.5	-27.5	-42.0	-14.7	-11.7	-196.2	-178.7	-91.6
11	-104.6	-92.2	-61.5	-99.4	-101.4	-35.0	-21.5	-5.7	-17.7	-136.4	-103.0	-86.5

The improvements due to adding height tend to be larger than those due to adding thickness. 500 hPa vorticity does not contribute to synoptic-climatological applicability of classifications: only three of 36 cases show significant improvement by adding vorticity, while a half of the cases show significant deterioration.

In summer, the improvements of the stratification of temperature due to adding heights and thickness are stronger in the southern part of Europe (D05 to D11) where the improvement is larger than in winter, and stronger for minimum temperature than for maximum temperature. Adding heights leads to the deterioration, mostly significant, for precipitation in northern and northwestern Europe (D01 to D05), whereas improvements, though mostly insignificant, appear in central, southern, and southeastern Europe (D06 to D11). Adding thickness leads to less improvements and more deterioration for precipitation than adding heights. Vorticity in summer brings an improvement in most domains for temperature and in several domains for precipitation (though not all improvements are statistically significant).

The change in performance due to simultaneously adding all the three input variables in both seasons reflects the changes due to single input variables: for both temperatures, improvements are observed in general, with the exception of D04 (and D01 in summer), while mostly deterioration is observed for precipitation, with the exception of southeastern and southern Europe (D08 to D11).

In an attempt to generalize, we may claim that the addition of more input variables into classification is most beneficial in southeastern Europe, whereas it results in least improvements or even a prevalent deterioration in the most maritime domains (D01, D04, D05). Vorticity has much smaller potential to improve the stratification of climate variables than mid tropospheric heights and lower tropospheric thickness.

4.3.5.4 Effect of seasonality

To determine the effect of seasonality of the definition of classifications, the classifications defined separately for four seasons (seasonal definition) are compared with those defined on the whole year (annual definition). Analogously to the previous section, the effect of seasonality of definition is quantified by subtracting ranks of each pair of classifications differing only in the seasonality, the other attributes (number of types, sequencing, additional variables) being equal. A negative difference indicates a lower rank for the classification with a seasonal definition, and hence its better performance. It is worth mentioning that the number of available pairs of classifications is lower than in the previous two comparisons, and consequently the confidence intervals around the mean differences are much wider, which results in lower significance for differences of the same magnitude. Another issue to point out is the fact that all seasonal classifications are designed to have 7 types; they are compared with the annual classifications with the designed number of types of nine. In view of a bias introduced by the unequal number of types in classifications compared, the results should be treated with caution since a part of the improvement, if there is any, may be attributable to the different number of types, not to the different definition of classifications.

Table 4.8: Effect of seasonal definition. Shown are mean differences in ranks between seasonal and annual classifications. Negative values indicate that seasonal definition leads to lower ranks, i.e., better stratification of the surface climate element. Otherwise as in Tab. 4.5

<i>Domain</i>	<i>Winter</i>			<i>Summer</i>		
	<i>TX</i>	<i>TN</i>	<i>RR</i>	<i>TX</i>	<i>TN</i>	<i>RR</i>
00	-44.0	-71.2	-46.4	-132.7	-94.5	-156.4
01	-40.6	-28.2	-17.1	-44.2	-54.7	-92.6
02	-75.2	-63.5	-35.1	-46.5	-14.6	-87.0
03	-15.5	-25.7	-55.4	+3.4	-17.0	-58.1
04	-37.8	-45.3	-36.2	-62.2	-49.4	-20.1
05	-42.5	-32.6	-21.9	-14.9	-29.0	-58.8
06	-26.1	-35.8	-30.5	-12.3	+18.6	-9.4
07	-27.1	-39.4	-28.9	-52.5	-39.5	-55.0
08	-36.8	-47.5	-19.6	-44.7	-57.3	-40.1
09	-38.1	-56.4	-61.6	-90.7	-84.0	-15.7
10	-16.9	-25.7	-25.5	-70.7	-64.5	-45.1
11	-44.9	-45.5	-17.0	-18.8	+36.9	+8.2

The effect of the seasonality of the definition is displayed in Tab. 4.8. The seasonal definition is better than the annual definition in almost all cases (all domains, all three target variables, both seasons), although the effect is not significant many times. Only four entries (all in summer) are of the opposite sign.

4.3.5.5 Effect of the number of types

To determine the effect of the number of types, two comparisons are conducted: one between classifications with around 9 and around 18 types, the other with classifications with around 18 and around 27 types. Analogously to previous sections, the effect of a higher number of types is quantified by subtracting ranks of each pair of classifications differing only in the number of types (higher minus lower), the other attributes (sequencing, input variables, seasonality) being equal. A negative difference indicates a lower rank for the classification with a lower number of types, and hence a deterioration due to an increase in the number of types.

Results are summarized in Tabs. 4.9 and 4.10 for winter and summer, respectively. Clearly, the tables confirm the theoretical expectations as well as results of the preliminary analyses in Sect. 4.3.4.3: The K-S test yields significantly better results for lower numbers of types. There are only few exceptions to this general finding, all occurring for summer and the comparison between 9 and 18 types: differences are in one case slightly positive, while in two other cases negative, but insignificant.

Table 4.9: Effect of the number of types, winter. Shown are mean differences in ranks between classifications with 9 and 18 types (left) and 18 and 27 types (right). Negative values indicate that fewer types lead to lower ranks, i.e., better stratification of the surface climate element. Otherwise as in Tab. 4.5

<i>Domain</i>	<i>9 vs 18</i>			<i>18 vs. 27</i>		
	<i>TX</i>	<i>TN</i>	<i>RR</i>	<i>TX</i>	<i>TN</i>	<i>RR</i>
00	-92.3	-91.3	-110.2	-44.7	-47.2	-62.1
01	-83.5	-82.0	-89.1	-55.8	-49.5	-61.0
02	-83.7	-76.3	-83.6	-53.6	-51.7	-52.7
03	-95.5	-85.1	-83.7	-39.8	-45.1	-45.6
04	-99.9	-94.0	-90.9	-51.1	-56.2	-59.4
05	-81.6	-80.9	-70.2	-43.2	-38.2	-58.0
06	-83.9	-83.4	-104.1	-54.7	-55.2	-53.2
07	-120.7	-106.1	-103.2	-38.7	-45.8	-51.9
08	-89.5	-77.9	-112.5	-45.1	-49.1	-56.9
09	-72.3	-92.0	-96.3	-71.3	-49.9	-61.7
10	-78.6	-82.6	-110.0	-59.2	-60.6	-73.2
11	-84.4	-75.2	-72.7	-47.7	-47.6	-50.1

Table 4.10: Effect of the number of types, summer. Otherwise as in Tab. 4.9

<i>Domain</i>	<i>9 vs 18</i>			<i>18 vs. 27</i>		
	<i>TX</i>	<i>TN</i>	<i>RR</i>	<i>TX</i>	<i>TN</i>	<i>RR</i>
00	-27.3	-7.6	+2.6	-39.1	-28.2	-29.1
01	-106.0	-101.9	-63.6	-43.4	-42.1	-31.5
02	-80.4	-83.2	-64.2	-39.8	-29.9	-32.7
03	-59.5	-72.9	-70.1	-35.6	-25.1	-35.3
04	-96.5	-77.2	-87.1	-46.5	-56.4	-32.9
05	-62.6	-57.1	-75.1	-34.4	-39.1	-36.9
06	-75.7	-69.8	-84.5	-21.9	-29.0	-30.3
07	-72.8	-72.1	-73.2	-31.2	-31.8	-31.7
08	-73.8	-64.0	-81.8	-19.4	-28.2	-29.5
09	-67.7	-72.4	-52.3	-31.8	-16.5	-35.4
10	-53.0	-65.0	-64.8	-13.4	-15.5	-32.0
11	-30.8	-38.0	-13.7	-43.0	-40.2	-17.9

4.3.6 Summary

The methods that manifest best synoptic-climatological applicability according to the criterion based on the K-S test are CKM, CAP, LIT, and GWT. On the other hand, the synoptic-climatological applicability of the PCT, PTT, LND, KIR, and ERP methods is systematically worse and their use in synoptic-climatological studies is not recommended.

However, there are large differences in the performance of methods among target variables, across domains, and between seasons.

There is a slight tendency to a better / worse performance on the large domain relative to the smaller domain for JCT, PXE, PCT, and to lesser extent PXK / GWT, LIT, KIR, and CKM.

The geographical differences in performance are not systematic in winter, whereas in summer, there are several methods tending to perform better in southern plus south-eastern and/or northern domains.

Sequencing improves the stratification of temperature especially in winter. The improvement is larger for minimum temperature, and furthermore largest for the large domain (D00). Sequencing leads to a deterioration of the stratification of precipitation.

The addition of mid-tropospheric heights and lower-tropospheric thickness tends to improve the stratification of temperature; the degree of improvement differs geographically (with least improvements in the maritime domains) as well as seasonally. The effect on precipitation is less systematic, and differs in sign from domain to domain. The addition of mid-tropospheric vorticity leads to a deterioration of the stratification of temperature and precipitation in winter, while in summer, both improvement and deterioration occur for all target variables. In general terms, additional input variables bring largest benefits in southeastern Europe, whereas in the maritime domains of western and northern Europe, classifications based on SLP only are sufficient to characterize surface climate conditions.

The seasonal definition of classifications leads to a better stratification of surface climate elements than the annual definition; the difference is more pronounced in winter.

Also, it was confirmed that the K-S test-based criterion favours classifications with lower numbers of types. Two warnings concerning the interpretation of results follow from this fact:

1. Results for the ranking of classifications may be biased because of the unequal numbers of non-empty types.
2. Results for the effect of seasonality may be affected by a systematically lower number of types in the seasonally defined classifications.

Another comment is related to the seasonality of the definition of classifications. The good performance of the LIT method may be due to the fact that its definition is in fact monthly-based: Separate thresholds used in LIT to define types are set in each calendar month. Therefore, its good performance may be a result of an implicit seasonality of its definition rather than of the method itself.

To confirm (or deny) results of the assessment of synoptic-climatological applicability by the K-S test, and to make them more generally valid, a similar analysis should also be conducted for other sensible measures of similarity, introduced e.g. by [HUTH et al. \(2008\)](#) and [BECK and PHILIPP \(2010\)](#).

4.3.7 Recommendations to other working groups

Results of the synoptic-climatological analysis using the K-S test fed back to the development of classifications in WG2. Three basic implications for WG2 have stemmed from this analysis:

1. Dependence of the quality of stratification on the number of types. This effect can be clearly seen for other evaluation criteria, too, although the direction of the effect may be opposite (while for the criterion based on the K-S test, the smaller numbers of types imply a better stratification, the opposite may be true for other criteria). Based on this observation, it was decided that the numbers of types in the classifications will be set as close to 9, 18, and 27 as possible wherever it is feasible in order to allow a fair comparison across methods.
2. Sequencing. A comparison of results between SANDRA and its sequential version SANDRA-S in the v1.2 version of the COST733 database (referred to as SAN in v2.0) suggested that sequencing may add some value to classifications ([HUTH, 2010](#)). Consequently, it was decided to produce sequenced versions of classifications for a selection of other methods as well.
3. Seasonality. The original implementation of the CKMEANS method (now referred to as CKM) in v1.1 of the database produced different sets of types in individual seasons: it produced ten types in each season, altogether yielding 40 types in the whole year. Preliminary results confirmed that such a seasonal approach leads to a better stratification of surface climate elements thanks to a better fit of individual types to reality in individual seasons. Therefore it was decided, in order to keep the comparability of individual classifications as high as possible, to define all the methods on a year-round, not seasonal, basis, and to use the seasonal definition as the option for those methods for which it is applicable and sensible.

4.4 How to quantify the resolution of surface climate by circulation types: Examples for Alpine and Norwegian Precipitation

Authors: Reinhard Schiemann and Christoph Frei

4.4.1 Introduction

Circulation type classifications (CTCs) aim at identifying recurrent dynamical patterns (of e.g., sea level pressure) for a particular region. The resulting set of circulation types (CTs) provides a simple conceptual framework where, ideally, the specific weather situation of a day can be attributed to one of the CTs. There is a wide range of possible meteorological, climatological, and hydrological applications of CTCs (see e.g., [TVEITO and PASQUI, 2005](#)) and Chapter 5 of this report). Their utility in a concrete case, however, depends on how closely the phenomenon under study is associated with the set of CTs, or – in statistical parlance – how good a predictor the factor circulation type is. Obviously, a comparative evaluation of the predictive capability of CTCs is desirable for choosing an appropriate CTC in a concrete application.

Several measures quantifying the predictive capability of CTCs have been suggested (e.g., [KALKSTEIN et al., 1987](#); [ROUSSEEUW, 1987](#)); see also [HUTH et al. \(2008\)](#) for an overview. Many existing measures rely on squared differences or some other sort of distance measure, to quantify the between-type variance against the total variance. When applied to skewed variables such as daily precipitation, many of these classical skill measures have limitations because of their emphasis on extremes.

In [SCHIEMANN and FREI \(2010\)](#), we have proposed a different method of evaluating and comparing the predictive skill of CTCs. The proposed procedure is suitable for situations where the phenomenon of interest can be formulated as a dichotomous (binary) event, e.g., the occurrence of frost/no-frost days. However, continuous variables are also amenable to this approach when examining the exceedance/non-exceedance of thresholds. The novelty of our approach consists in treating the CT as a probabilistic binary forecast and, accordingly, the evaluation procedure builds on a skill score commonly used for the evaluation of probabilistic or ensemble forecasts, namely the Brier skill score. We have also proposed a resampling procedure to quantify the sampling uncertainty and to test for statistical significance of the skill score, which is essential to interpret differences in skill between classifications.

We illustrate the proposed evaluation scheme in a concrete application, quantifying the ability of CTCs to describe day-to-day variations of mesoscale precipitation in the Alpine region. The distribution of precipitation in this region is complex and responds critically to the patterns of the larger-scale circulation. Our application is therefore an interesting test case.

An issue not addressed in [SCHIEMANN and FREI \(2010\)](#) is the question of how robust the results are with respect to the choice of the geographical domain. If some CTCs were based on a superior classification methodology, they should represent a climate variable (here precipitation) particularly well and consistently so for different domains. In a Short Term Scientific Mission by R. Schiemann to the Norwegian Meteorological Institute ([SCHIEMANN et al., 2009](#)), the evaluation of classifications was extended to CTCs for a Scandinavian domain and to Norwegian precipitation data in order to give

a preliminary answer to the question of domain dependence.

4.4.2 Data

In the application of our evaluation procedure, we compare a total of 71 CTCs, automatic and manual, from versions 1.1 and 1.2 of the COST733 catalogue of CTCs (PHILIPP et al., 2010), and for the Alpine (D06) and Scandinavian (D02) COST733 standard domains. Furthermore, gridded precipitation datasets of mesoscale and daily resolution have been used. For the Alps this is the dataset described in FREI and SCHÄR (1998) and FREI et al. (2006) through 1971–1999, and for Norway the data described in MOHR (2008) and MOHR and TVEITO (2008) through 1981–1990.

4.4.3 Evaluation method

The Brier skill score is widely used as a measure of skill of probabilistic meteorological forecasts [BRIER (1950); see also WILKS (2006) and WEIGEL et al. (2007)]. As shown in SCHIEMANN and FREI (2010), it takes a particularly simple form in the context of CTC evaluation:

$$BSS = \frac{\frac{1}{N} \sum_{i=1}^I N_i (y_i - \bar{o})^2}{\bar{o}(1 - \bar{o})} \quad (4.7)$$

Here, N is the number of days in the observation period, $i = 1 \dots I$ denotes the types of the classification, N_i is the number of days with CT i , y_i is the relative frequency of an event (here, the exceedance of a precipitation threshold) in CT i , and \bar{o} is the unconditional (climatological) relative frequency of the same event.

BSS is the normalized resolution component of the Brier skill score. In our context, the other components of the Brier skill score (reliability and uncertainty) vanish, but we keep calling it the Brier skill score. BSS varies between 0 and 1, with larger values indicating more skill. Confidence intervals for the BSS are obtained by means of non-parametric bootstrap resampling (see SCHIEMANN and FREI, 2010, for details).

4.4.4 Findings summary

We find that the skill with which COST733 CTCs represent precipitation threshold exceedance in the Alps depends on the following factors: (i) The predefined precipitation threshold: classifications systematically better resolve the occurrence of low to moderate precipitation events, compared to rarer heavy precipitation (Fig. 4.42). (ii) The season of the year: for all classifications, the skill is clearly larger during winter than summer. Spring and autumn scores are in between with spring (autumn) being closer to summer (winter). (iii) The number of circulation types: classifications with larger type numbers generally achieve better skill than those with low type numbers. (iv) The location: many classifications depict a similar pattern with higher skill to the west and north of the Alps, and lower skill to the south and east of the Alps. All these findings appear consistent with simple arguments regarding the relationship between the synoptic-scale circulation and the mesoscale precipitation distribution.

When comparing the skill between individual classifications, their relative ranking is fairly similar for different choices of the precipitation threshold and also for different values of the number of types. However, this does not hold for the seasonal and spatial

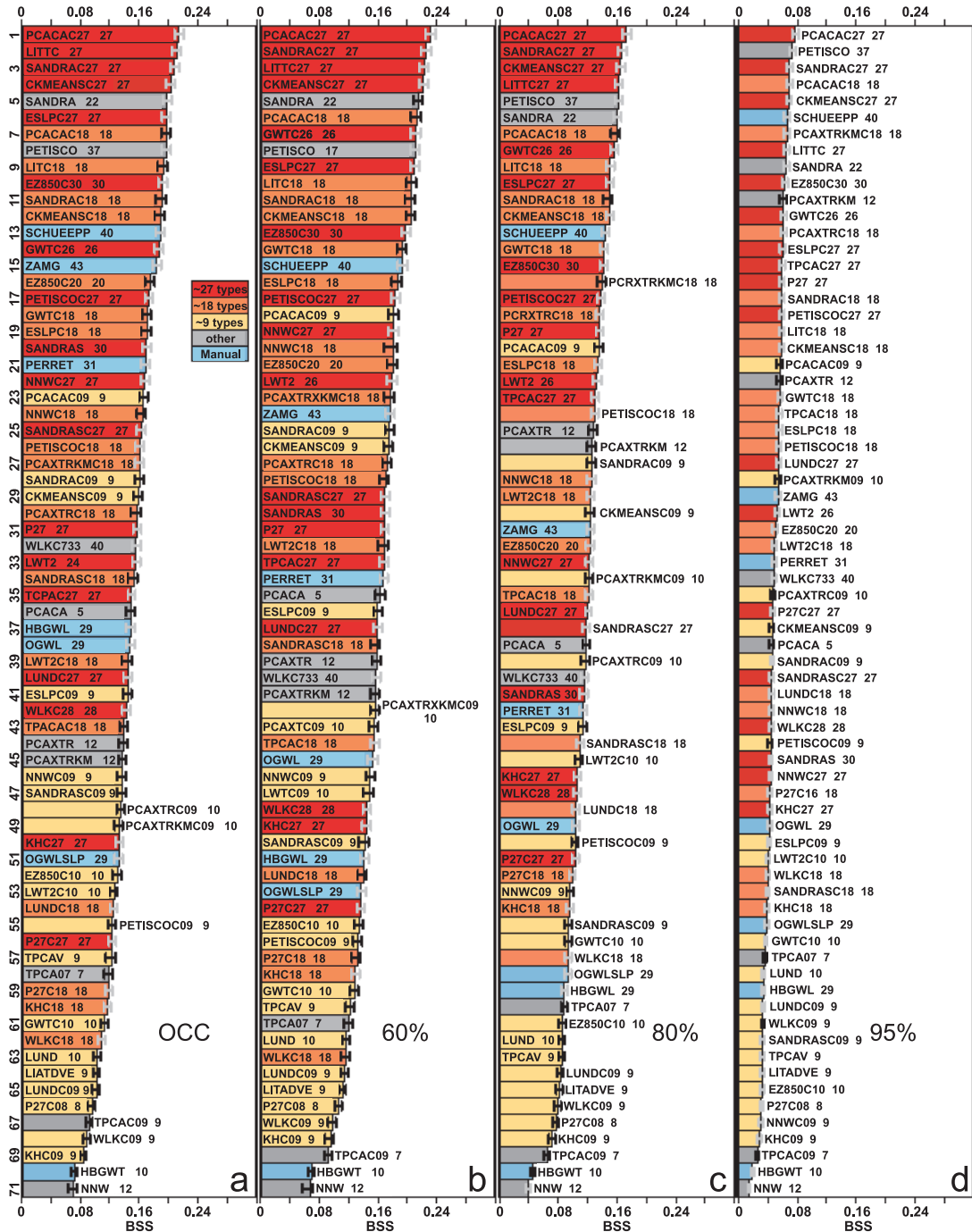


Figure 4.42: Brier skill scores for different thresholds: (a) precipitation occurrence threshold, (b–d) exceedance of the 60%, 80%, and 95% quantiles. Each horizontal bar shows the score for the whole year and averaged over the Alps (4.0–17.5°E, 43.5–49.0°N) for one classification. Bar colours distinguish classifications with ≈ 27 (red), ≈ 18 (light red), ≈ 9 types (yellow), other type numbers (grey), and manual classifications (blue). 95% Bootstrap confidence intervals are shown in black (BCa method) or grey (debiased percentile intervals).

dependence. CTCs scoring well in winter are not necessarily also among the best in summer. Moreover, while the automatic classifications have a fairly similar spatial skill

pattern, the manual classifications tend to have a high skill in the regions they were designed for.

In general, we find that the best automatic classifications clearly outperform the manual classifications, even when the latter have more types. Exceptions to this are the manual SCHUEEP and ZAMG classifications, which score similarly to the best automatic classifications in summer and for parts of Austria, respectively. Since these two manual classifications have many more types than the automatic CTCs, we cannot objectively compare manual and automatic CTCs in these situations. Among the automatic classifications, there are considerable differences in skill. While there is no single ‘best’ classification that stands out from all others when taking sampling uncertainty into account, a small group of automatic CTCs performing particularly well can be identified.

The results of the analysis for CTCs in a Scandinavian domain and precipitation in Norway are in many respects similar to the results obtained for the Alps. A mentionable difference concerns the amplitude of the seasonal cycle of the *BSS* values. For Norway, the seasonal cycle is much less pronounced. This appears to be due to the fact that there is a less clear distinction between a winter regime of stratiform precipitation (largely controlled by the large-scale circulation) and a summer regime of predominantly convective precipitation than in the Alpine region. Moreover, also the ranking of CTCs according to their skill is more similar across the seasons for the Norwegian domain.

It is interesting to note that many of the classifications that were found to have very high skill in the Alps also have comparatively high skill over Norway. This points to the fact that the skill values may not be coincidentally high for a given study area, but are robust and can be attributed to the classification methodology. Analyses for further regions would be necessary in order to corroborate or discard this hypothesis.

4.5 Evaluation of the cost733-cat-2.0 catalogue based on Spearman's rank correlation coefficient

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4.5.1 Description of the method

4.5.1.1 Main assumptions of the method

The applied method performs an evaluation of the field of the value of Spearman's rank correlation coefficient (RS) between circulation types (CT) and defined types of meteorological elements (TME). Calculations were carried out for the period 09/1957–08/2002 using ERA40 data. The patterns of the TME were defined at every grid points of the considered domain. They are:

1. thermal: 2mT – 2 metre temperature
2. precipitation: sums of CP – Convective precipitation and LSP – Large scale precipitation.

General comparison of classification has been carried out by evaluating the field of the coefficient RS .

4.5.1.2 Definitions and the characteristics of applied types of the weather

In this work three-class (A) and six-class (B) types of the temperature and the precipitation are defined. This was done for each day at each grid point with respect to the mean values (μ) and standard deviations (σ) which were also calculated for each grid point. The definitions of weather patterns and histograms of frequency in each domain for all grid points are given below.

Figs. 4.43 and 4.44 show histograms for the temperature-related types A and B, respectively. How the temperature or precipitation patterns have been designed is indicated in the figure captions. The height of the bars indicates the frequency of occurrence of temperature (or precipitation) patterns calculated for all grid points in the domain for the whole period 1957–2002. The histograms in Figs. 4.45 and 4.46 display the frequencies of the precipitation-related types. The assignment of the intervals used in the histograms can be found in the figure captions.

For the temperature, the intervals were determined on the basis of the mean value and standard deviation and the resulting distributions are very similar for all domains. Intervals for precipitation have been derived on the basis of the percentage of the average precipitation sum and there is more variability/dissimilarity between the histograms.

Weather pattern A (three-tier) for the temperature

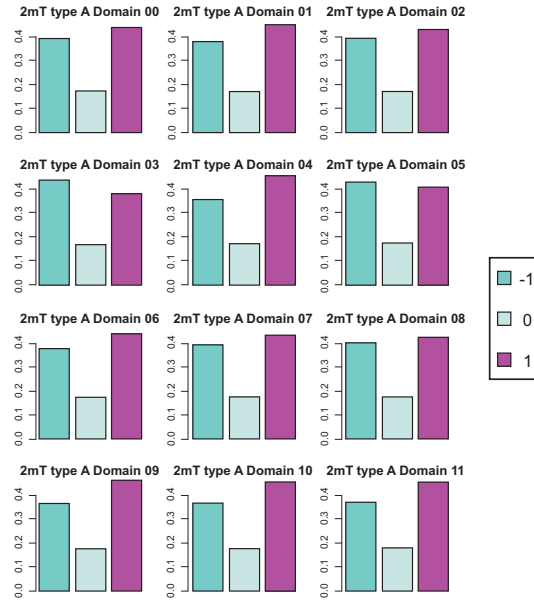


Figure 4.43: Histograms of temperature type A. Code -1: $2mT < \mu - 0.25\sigma$ (cold); code 0: $[\mu - 0.25\sigma, \mu + 0.25\sigma]$ (average); code 1: $2mT > \mu + 0.25\sigma$ (warm).

Weather pattern B (six-tier) for the temperature

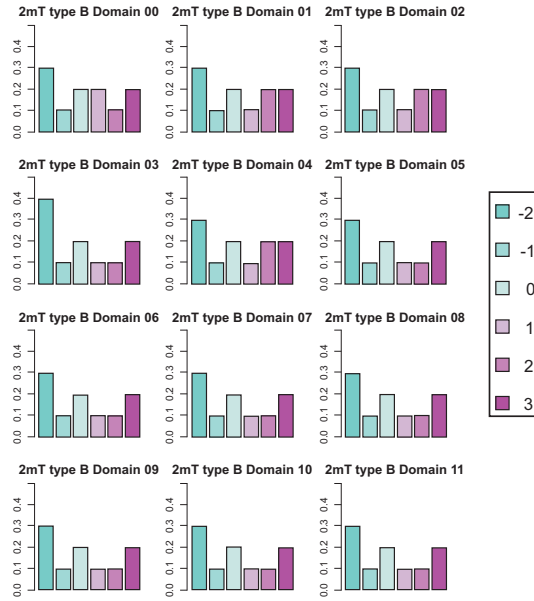


Figure 4.44: Histograms of temperature type B. Code -2: $2mT < \mu - 0.5\sigma$; code -1: $[\mu - 0.5\sigma, \mu - 0.25\sigma]$; code 0: $[\mu - 0.25\sigma, \mu + 0.25\sigma]$ (average); code 1: $[\mu + 0.25\sigma, \mu + 0.5\sigma]$; code 2: $[\mu + 0.5\sigma, \mu + \sigma]$; code 3: $2mT > \mu + \sigma$.

Weather pattern A (three-tier) for the precipitation

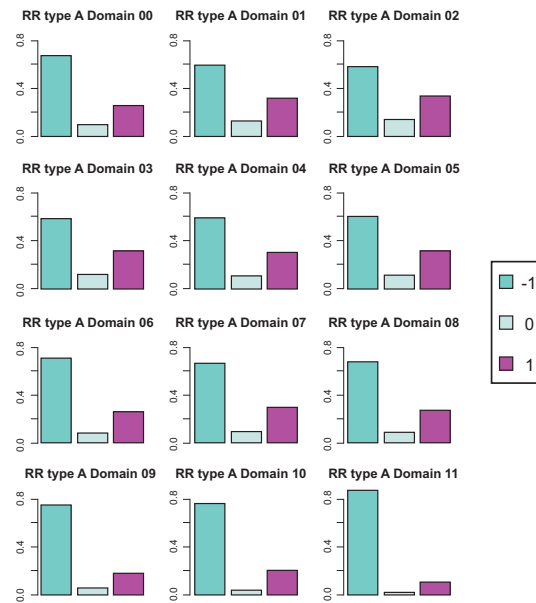


Figure 4.45: Histograms of precipitation type A. Code -1: $LSP+CP < 50\%$ (“dry day”); code 0: $LSP+CP$ in $[50\% \mu - 100\% \mu]$ (“average”); code 1: $LSP+CP > 100\% \mu$ (“wet day”).

Weather pattern B (six-tier) for the precipitation

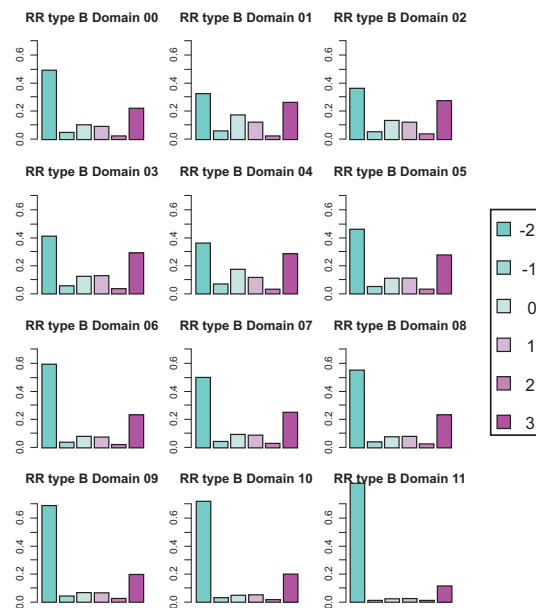


Figure 4.46: Histograms of precipitation type B. Code -2: $LSP+CP < 25\% \mu$; code -1: $LSP+CP$ in $[25\% \mu, 50\% \mu]$; code 0: $LSP+CP$ in $[50\% \mu, 75\% \mu]$; code 1: $LSP+CP$ in $[75\% \mu, 100\% \mu]$; code 2: $LSP+CP$ in $[100\% \mu, 125\% \mu]$; code 3: $LSP+CP > 125\% \mu$.

4.5.1.3 Methods of assessing the quality of CT classification

The field of the correlation coefficient enables to define several ways to assess the quality of CT classifications. For example it is possible to define related conditions based on simple statistics of the field.

Here, the field of the calculated coefficients was evaluated on the basis of descriptive statistics: Min - the minimum value, $Q1$ - the 1-quantile, Me - the median are employed to define the following quality criteria:

- The condition $RS_{Min} > 0.2$ means that for the whole domain at least a weak correlation between the classification and the TME can be detected;
- the condition $RS_{Q1} > 0.2$ means that a weak correlation is present in at least 3/4 of the domain;
- the condition $RS_{Me} > 0.2$ means that at least over half of the domain a weak correlation occurs between the classification and the TME.

The following procedure is pursued:

- assess the number of classifications that meet the criterion;
- choose the best classification based on the value of the adopted statistics.

For example the quality of the methods applied in the classifications of CTs may be evaluated according to the first method. The median was selected from a set of basic statistics for the RS field, as measures of the relationship of the classification with the TME. The value greater than 0.2 was adopted as a condition of acceptance of the classification system CT to be appropriate for determining the TME. An example for domain D07 and precipitation RR is given in Fig. 4.47. It shows two plots, on the left the bars correspond to the frequencies and on the right the bars correspond to the percentage participation of each group of CT classification methods.

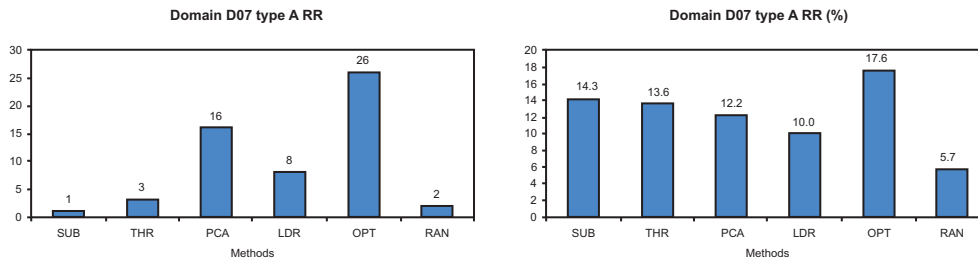


Figure 4.47: Statistics of the choice of the classifications CT for the domain D07.

Based on Fig. 4.47 it can be concluded that, for Domain D07, issues with precipitation should be analyzed using the classifications from the group OPT (the highest percentage of classifications that meet the criterion amounts to 17.6% for OPT). This method was used to obtain the results presented in Sect. 4.5.2 and 4.5.3. The analysis of the quality of a classification by the second method, which consists of an analysis of the field values of the correlation coefficient, is presented in Sect. 4.5.4.3 and 4.5.4.4.

4.5.2 Results for the temperature patterns

When choosing the appropriate classification CT for the temperature patterns, the condition was identified as $RS_{Q1} > 0.2$. The criterion proved to be very sharp in this case. In the case of three-tier patterns (A) only four classifications could be identified. They are listed in Tab. 4.11.

Table 4.11: Classifications selected for a three-class type of temperature (A).

No.	Meth.	Name	Dom.	YR/SE	Input	RS					
						min	1st Qu	med.	mean	3rd Qu	max
1	PCA	KRZ09	D05	YR_S01	SP-Z5	0.03	0.20	0.24	0.22	0.26	0.29
2	PCA	KRZ18	D05	YR_S01	SP-Z5	0.03	0.21	0.25	0.23	0.27	0.30
3	PCA	KRZ27	D05	YR_S01	SP-Z5	0.04	0.21	0.25	0.23	0.27	0.30
4	PCA	PXE10	D06	YR_S04	SP-Y5	0.18	0.23	0.25	0.25	0.27	0.32

Tab. 4.12 contains the CT classifications selected for the six-tier temperature patterns (B). These were the same CT classifications, i.e., KRZ09, KRZ18, KRZ27 and PXE10 – only classification KRZ also fulfills the criterion in Domain D03.

Table 4.12: Classifications selected for a six-class type of temperature (B).

No.	Meth.	Name	Dom.	YR/SE	Input	RS					
						min	1st Qu	med.	mean	3rd Qu	max
1	PCA	KRZ09	D03	YR_S01	SP-K5	0.05	0.21	0.26	0.25	0.30	0.32
2	PCA	KRZ09	D05	YR_S01	SP-Z5	0.01	0.22	0.26	0.24	0.28	0.32
3	PCA	KRZ18	D03	YR_S01	SP-K5	0.05	0.21	0.27	0.25	0.31	0.34
4	PCA	KRZ18	D05	YR_S01	SP-Z5	0.02	0.23	0.27	0.25	0.30	0.33
5	PCA	KRZ27	D03	YR_S01	SP-K5	0.05	0.21	0.27	0.26	0.31	0.34
6	PCA	KRZ27	D05	YR_S01	SP-Z5	0.02	0.23	0.27	0.25	0.30	0.33
7	PCA	PXE10	D06	YR_S04	SP-Y5	0.18	0.24	0.26	0.26	0.29	0.33

All methods which were chosen are from the group of CT classifications based on principal components, PCA. Furthermore, all the selected classifications are based on the expanded set of input parameters (SP-K5, SP-Z5, SP-Y5).

4.5.3 Results for the precipitation patterns

The selection criterion adopted was the same as in the case of the temperature patterns. For the precipitation patterns significantly more cases of the CT classification were selected, i.e., 52 for type A and 61 for type B. They contain PCA methods but also optimization methods (OPT), e.g., CAP, CKM and SAN. Spearman's correlation coefficient reached the appropriate value in the domains D01, D02, D03, D04 and D05. The maximum value of RS was as high as 0.5 in six cases. In one case for precipitation pattern B, the criterion was met for the domain D06 for the optimization method SAN.

The maximum value of the RS ratio reached 0.5 in twelve cases. Most of the selected classification are based on the expanded set of input parameters. Only two of the CT classification selected for the patterns types A and B were based exclusively on the sea level pressure.

4.5.4 Results for the sorting procedure

4.5.4.1 Description of procedures for comparing classifications

Spearman's rank correlation coefficient (RS) describes the linear correlation of ranks of elements of the sample, hence is a measure of any monotone correlation between the tested samples. In order to exploit this property of RS , the order numbers have been assigned to the circulation types (CT), which were generated based on the connection with the conditional probability of occurrence of a selected TME. In this study, the first pattern containing extreme weather (very cold, very dry) was selected. To circulation classes were given the number corresponding to the ranks of the probability. Circulation types were assigned numbers (values) corresponding to the order of decreasing conditional probability of occurrence of selected weather patterns (SWP). This assignment was carried out at any point of the grid independently.

$\{CT_j\}$ – sequence of types of circulation at the point of grid;

$\{WP_j\}$ – sequence of weather patterns at the point of grid;

$\{p_i\}_{i=1}^{i=N_C}$ – sequence of conditional probabilities of the selected temperature or precipitation pattern, where N_C – number of classes in the system of CT classifications.

$p = p(WP = SWP|CT = i)$ – this is the conditional probability of SWP , under the condition that the circulation type $CT = i$, for $i = 1, \dots, N_C$.

The series $\{p_i\}_{i=1}^{i=N_C}$ were sorted in ascending order.

$\{p_i\}_{i=1}^{i=N_C} \Rightarrow \{q_i\}_{i=1}^{i=N_C}$ where $q_1 \leq q_2 \dots q_{N_C}$ and

$q_1 = p_{O(1)}$ where $O(1)$ is the number of classes according to COST733CAT-2.0 for which p has rank 1 in the sorted series $\{q_i\}_{i=1}^{i=N_C}$;

$q_k = p_{O(k)}$ where $O(k)$ is the number of classes according to COST733CAT-2.0 for which p has rank k in the sorted series $\{q_i\}_{i=1}^{i=N_C}$;

$q_{N_C} = p_{O(N_C)}$ where $O(N_C)$ is the number of classes according to COST733CAT-2.0 for which p has rank N_C in the sorted series $\{q_i\}_{i=1}^{i=N_C}$;

The new numbering of the classes of circulation CT is expressed by this formula:

$$S(k) = O^{-1}(k).$$

The sequence of the circulation types was transformed according to the formula:

$$\{CT_j\} \Rightarrow \{\overline{CT_j} = S(k) \text{ where } CT_j = k\}$$

The new numbering of the circulation classes, i.e., the new “value”, expresses the link between circulation types with the selected temperature of precipitation pattern. Through the sorting of the class, a meaningful link to the type of the temperature or precipitation patterns was achieved. When applying the sorting procedure the posed criteria are more restrictive.

4.5.4.2 Evaluation on the basis of the number of CT fulfilling the criteria

For calculations using the processed values of circulation types, the selection criterion has been made sharper. The condition $MinRS > 0.2$ means that there is a demand at least for a weak linear correlation for the entire domain. Tabs. 4.13 and 4.14 contain information about the number of CT classifications satisfying the condition mentioned above. The procedure for calculating Spearman's correlation coefficient which is explained in the previous section, allows to choose a much larger number of CT classifications, even with a much sharper criterion.

The quantities of selected classifications for type A and B are very similar. Tab. 4.13 shows the number of classifications that meet the criterion divided into: group of methods, domain, seasonality and the length of the averaging period.

Table 4.13: Statistics of selected classification. *): case-only method name and the number of classes; **): case-only method name and the number of classes and the type of input data.

	<i>Number of</i>							
	<i>selected</i>	<i>selected</i>	<i>selected</i>					
	<i>CT</i>	<i>CT*</i>	<i>CT**</i>	<i>domains</i>	<i>YR</i>	<i>SE</i>	<i>S01</i>	<i>S04</i>
WP A for 2mT	1662	96	384	11	1427	235	959	703
WP B for 2mT	1705	100	403	11	1472	233	1003	702
WP A for RR	936	125	332	8	833	103	802	134
WP B for RR	981	128	326	8	874	107	860	121

The number of domains for which suitable CT classifications were found, also grew substantially: 8 for RR and 11 for 2mT. However all of the analyzed CT classifications fulfilled the criteria adopted in Domain D00. Tab. 4.14 shows the number of classifications that meet the criterion for each domain.

Table 4.14: The count of classifications selected for each domain and the weather patterns (WP).

<i>Domain</i>	<i>WP 2mT type A</i>	<i>WP 2mT type B</i>	<i>WP RR type A</i>	<i>WP RR type B</i>
D00	0	0	0	0
D01	150	146	137	117
D02	228	231	130	122
D03	180	197	133	146
D04	163	158	245	213
D05	206	217	176	201
D06	161	155	53	64
D07	180	179	56	99
D08	160	164	6	19
D09	99	117	0	0
D10	77	75	0	0
D11	58	66	0	0

In that case for domains D00, D09, D10, D11 the criterion became weakened and selection results are presented in Tab. 4.15. The new criterion was not applied to the minimum of the value RS_{Min} , but only to the value of the first quantile RS_{Q1} . This means that the weak linear rank correlations appears not on the entire area of a domain but only on three-quarters of its area. Further calculations showed that in this instance it was successful to choose suitable classifications for the considered domains.

Table 4.15: The count of classifications selected with the weakened criterion for domains D00, D09, D10 and D11.

<i>Weather Pattern</i>	<i>Number of WTC</i>			
	<i>D00</i>	<i>D09</i>	<i>D10</i>	<i>D11</i>
2mT type A	109	345	292	264
2mT type B	130	352	282	287
RR type A	47	269	316	3
RR type B	67	272	345	3

Table 4.16: The classifications chosen in the domain D11 according to RR type A (top) and RR type B (bottom).

<i>RS</i>										
<i>Nr.</i>	<i>Meth.</i>	<i>Name</i>	<i>YR/SE</i>	<i>Input</i>	<i>Min</i>	<i>1st Qu</i>	<i>Median</i>	<i>Mean</i>	<i>3rd Qu</i>	<i>Max</i>
1	PCA	PXE17	YR.S01	SP-Z5	0.05	0.20	0.32	0.28	0.36	0.44
			-Y5-K5							
2	OPT	PXK17	YR.S01	SP-Z5	0.05	0.20	0.34	0.29	0.38	0.44
			-Y5-K5							
3	OPT	PXK17	YR.S01	SP-Z5	0.05	0.20	0.33	0.29	0.37	0.44

<i>RS</i>										
<i>Nr.</i>	<i>Meth.</i>	<i>Name</i>	<i>YR/SE</i>	<i>Input</i>	<i>Min</i>	<i>1st Qu</i>	<i>Median</i>	<i>Mean</i>	<i>3rd Qu</i>	<i>Max</i>
1	PCA	PXE17	YR.S01	SP-Z5	0.05	0.20	0.34	0.30	0.39	0.48
			-Y5-K5							
2	OPT	PXK17	YR.S01	SP-Z5	0.05	0.20	0.36	0.31	0.40	0.49
			-Y5-K5							
3	OPT	PXK17	YR.S01	SP-Z5	0.05	0.20	0.35	0.30	0.39	0.48

The fields of Spearman's correlation coefficient describe the spatial distribution of the strength of the relationship between the circulation types and the temperature or precipitation patterns. The results obtained suggest that for these domains there is evidence that the temperature/precipitation type maybe not strongly linked with the CT classifications. Most likely this is connected with the influence of the Mediterranean Sea on adjacent Domains.

The smallest number of classification has been chosen for the domain D11 and the precipitation. In any case, these were the same classifications for type A and type B. Tab. 4.16 shows the CT classifications selected for the domain D11.

A convenient tool to the description of the relation between fields is the Taylor dia-

gram. It allows the simultaneous display of the average distance among fields, the correlation and the standard deviation. The example in Fig. 4.48 shows Taylor diagrams for domains D00, D09, D10, D11 for the weaker criterion. The field of RS coefficients for the classification with the best descriptive statistics was chosen as a reference field.

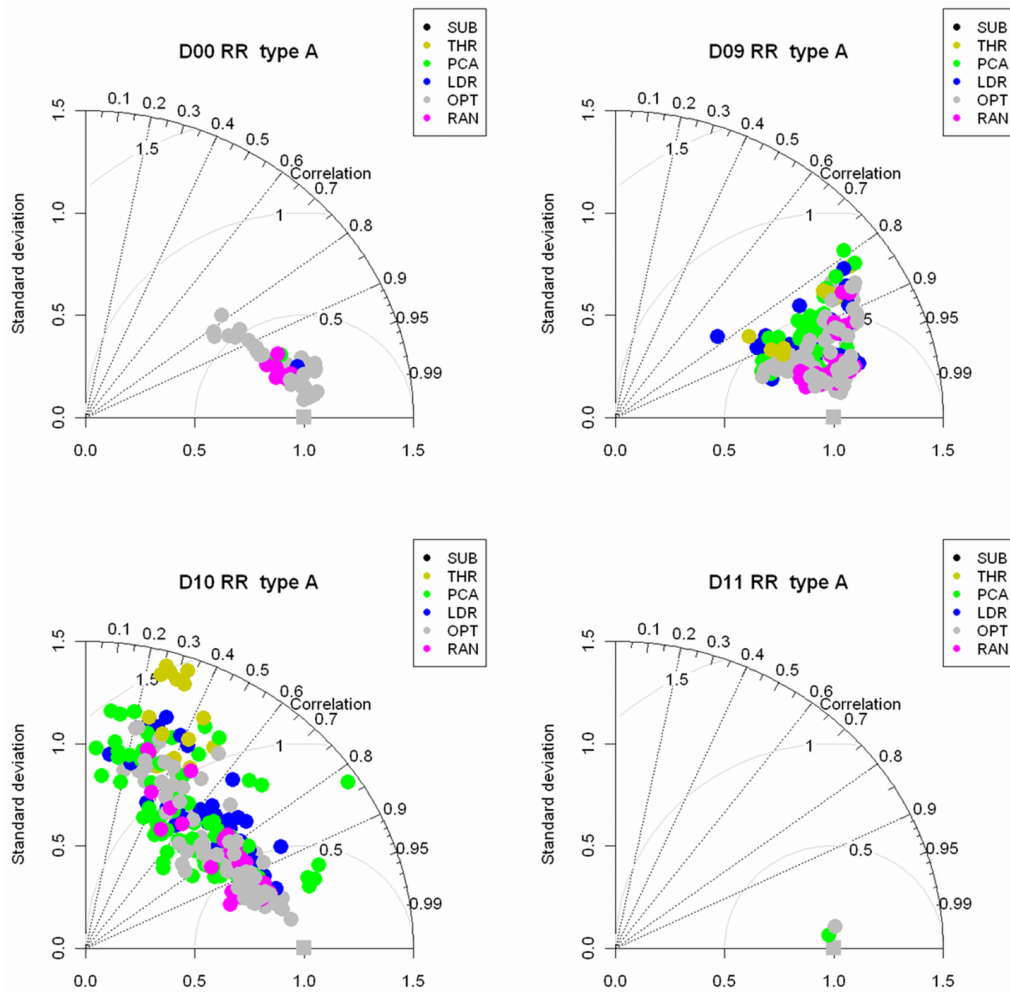


Figure 4.48: Taylor diagrams for RS fields for domains D00, D09, D01 and D11.

If a point lies near the reference point the quality of the classification is close to the quality of the chosen classification.

4.5.4.3 Comparison of the classifications of CT from group SUB – subjective

The classification in group SUB were compared using the median of the field of coefficient $RS(RS_{Me})$. Figs. 4.49 and 4.50 show the values of median of the field RS for all members of SUB group and for all domains, Fig. 4.49 for weather types A and Fig. 4.50 for weather types B.

For both types of the weather A and B values of RS_{Me} are arranged similarly and generally values for temperature 2mT are higher. Only GWLo occurs for two numbers

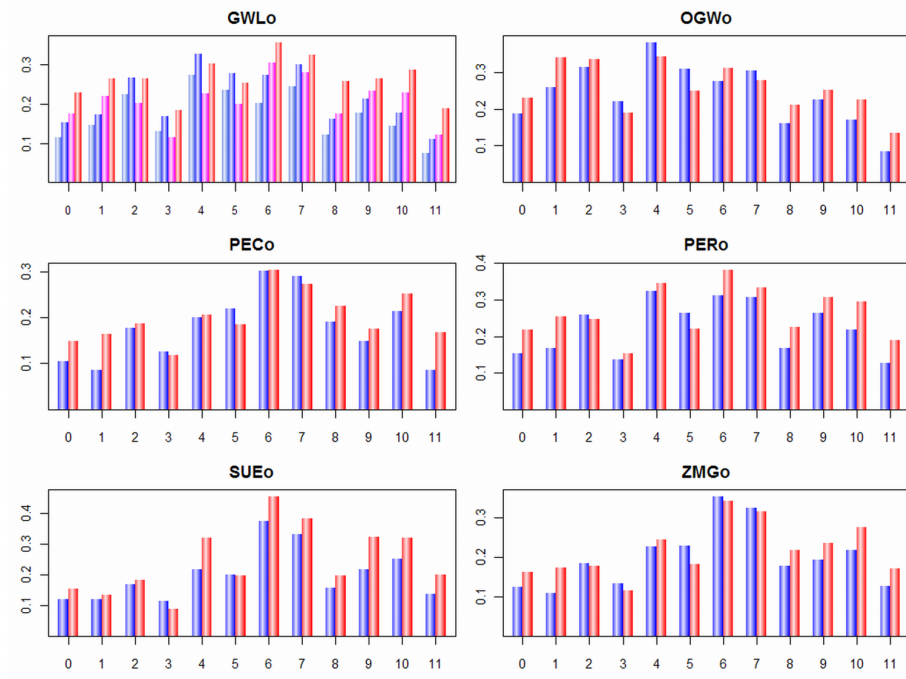


Figure 4.49: Bar graph showing the median of RS field for weather types A.

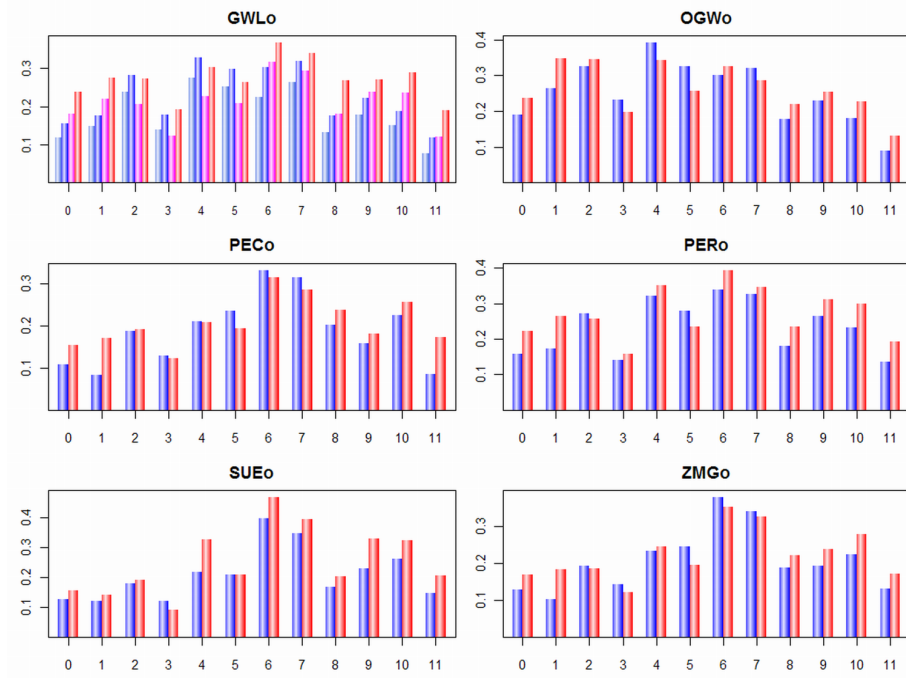


Figure 4.50: Bar graph showing the median of RS field for weather types B.

of classes 11 and 30 and higher RS values are achieved for larger number of classes. The highest value is reached in the domain D06 for all the CT except OGWo, for which the maximum occurs in the domain D04. For these cases, a picture of the RS field isoclines shown in Figs. 4.51 and 4.52, isoclines are marked in blue for the RR and in magenta for RR.

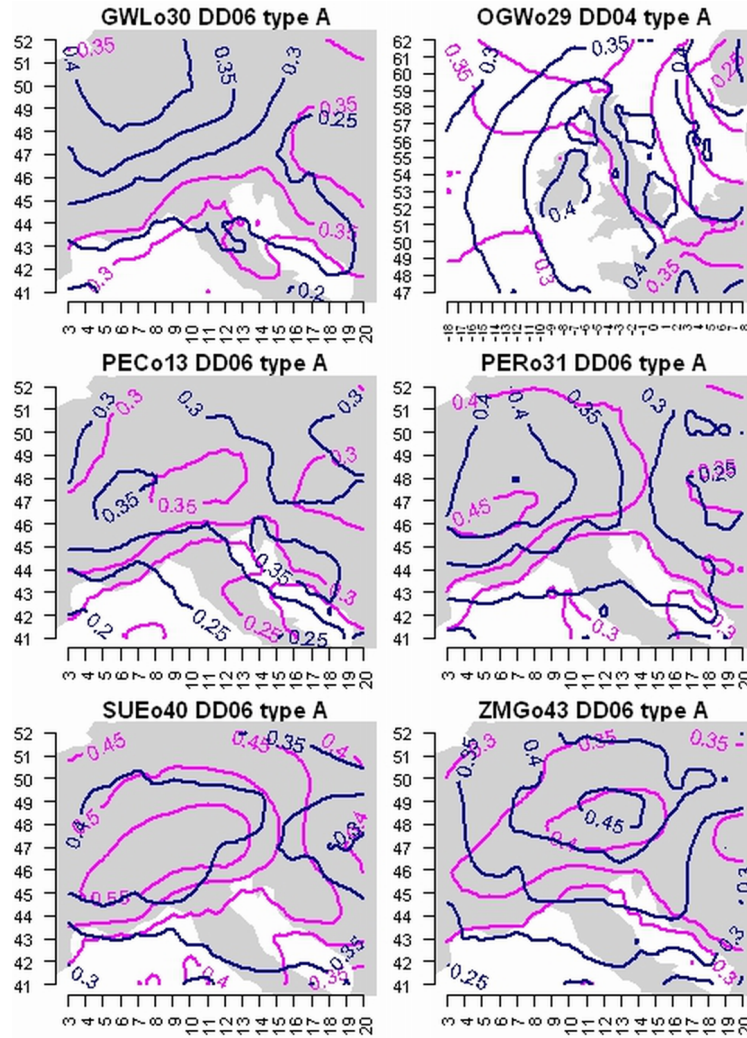


Figure 4.51: Isoclines of RS for CT and weather type A.

The highest value of RS_{Me} was achieved by SUEo(0.5) and in this case appears an area common for 2mT an RR where $RS > 0.4$.

4.5.4.4 Comparison of the classification of CT on the basis of the median field of RS

In each domain and for each of the 35 types of CT has been selected the best classification based on the median of the RS field. Due to the fact that the results for the weather types A and B are analogous results are presented only for type B. The selection condition was defined as the average of the median values RS_{Me} over all domains. Fig. 4.53 shows a graph of the median for the field of correlation coefficients RS for the patterns of temperature (red line) and rainfall patterns (blue line), averaged over the domains of D00-D11.

The lowest values refer to the classification of the subjective group SUB. The highest values relate to the classification based on optimization methods, except NNWo classification.

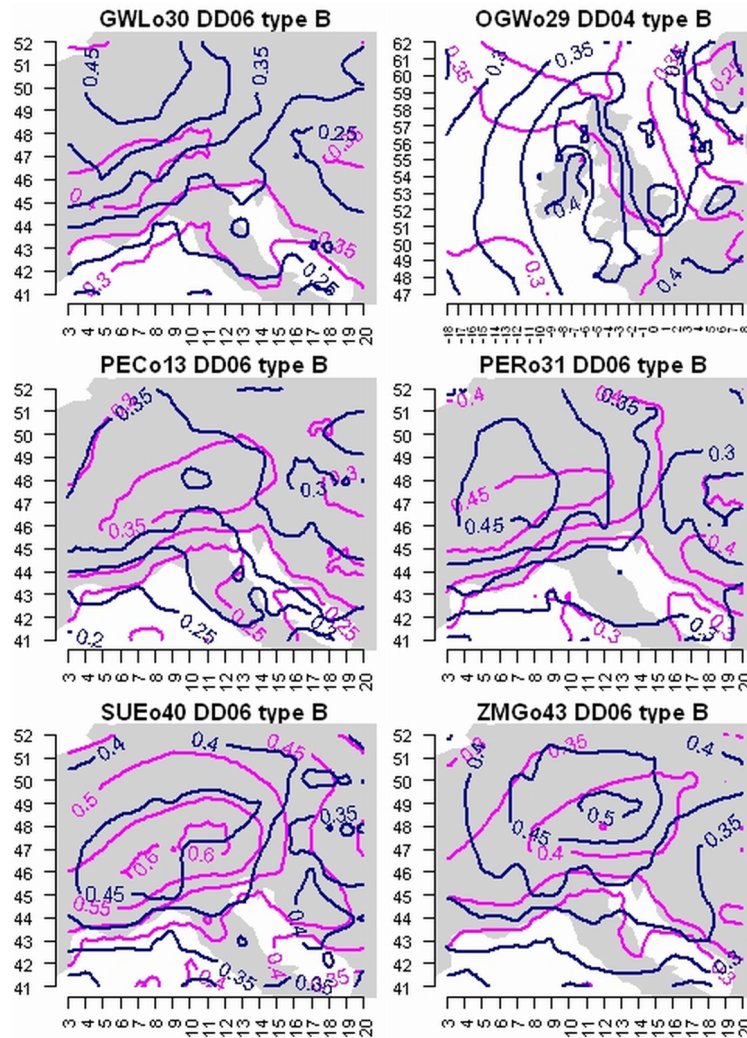


Figure 4.52: Isoclines of RS for CT and weather type B.

As a rule, where there were different number of classes , the classifications CT with the highest number of classes were selected.

Figs. 4.54 and 4.55 show the graphs for the median of the field of correlation coefficients RS for temperature patterns (Fig. 4.54) and rainfall patterns (Fig. 4.55), for selected CT classification.

For the value of RSMe below the threshold correlation (0.2) a value of 0.0 was inserted. This way, it is possible to select those of the classifications (domain and type of CT) for which RS is above the accepted threshold. Frequently, this procedure excluded the classifications CT in the domain D00 and the SUB group. Differences in values of RS for the classification in the domains point to the fact that it is impossible to select a single classification for all domains. The selection was done separately for temperature and precipitation.

This type of selection was tested in terms of uniformity of choice for both meteorological parameters and the results were shown in Tab. 4.17. For the subjective group of classifications SUB, the choice was the same for both temperature patterns and precipitation patterns.

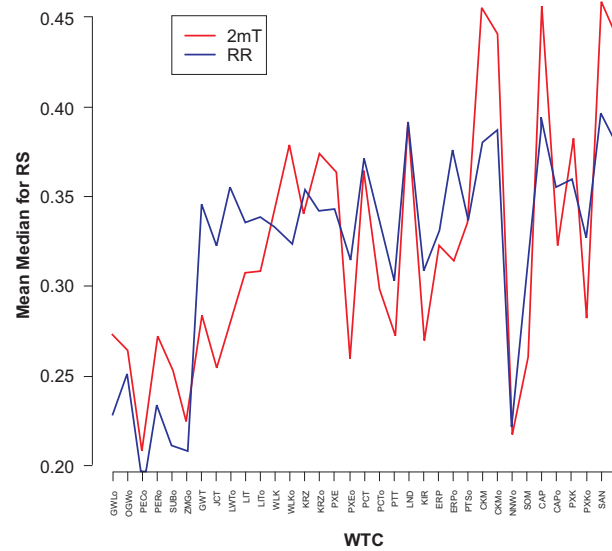


Figure 4.53: Plot of the median value of the RS field (averaged over all domains) for the selected version of the CT.

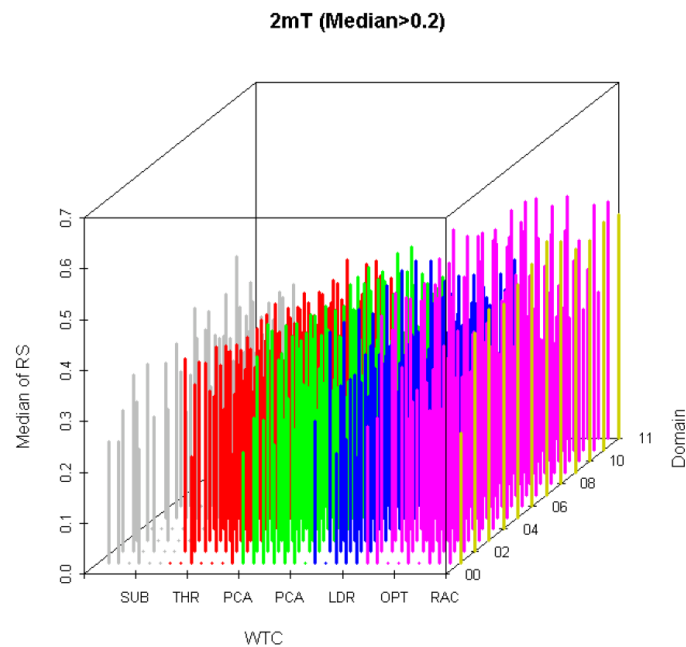


Figure 4.54: Bar graph of RS_{Me} for selected classification for temperature 2mT.

For the group of methods based on thresholds THR, only the classification WLKo has a different choice. For WLKo, the same classifications were selected only in the domain D00 and D06.

For the classifications CAP, CKM, SAN and RAC the choices for temperature and precipitation were different in each domain. In many cases the same choice was determined by the lack of modifications for the classification. Frequently, in cases where it was possible, one classification proved to be the best for the precipitation and the other for temperature.

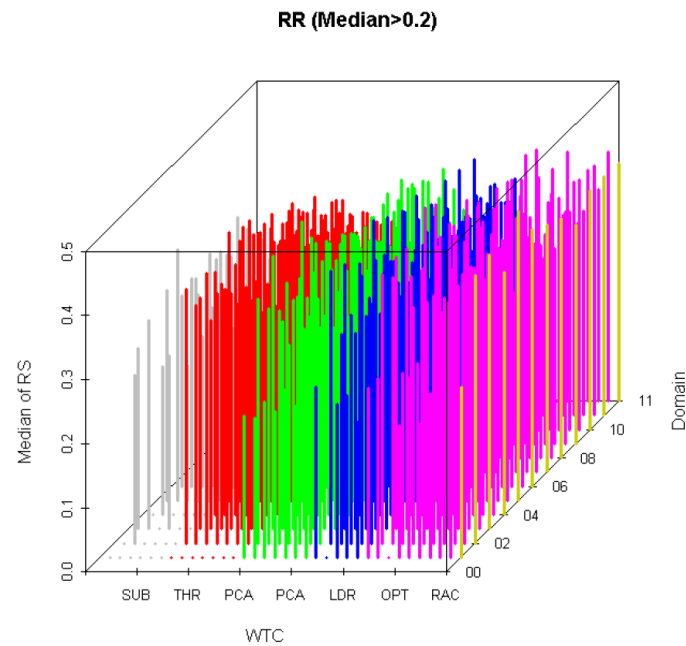


Figure 4.55: Bar graph of RS_{Me} for selected classification for precipitation RR.

Table 4.17: Table similarity of the choice of classification suitable for the precipitation and for the temperature.

<i>WTC</i>		<i>D00</i>	<i>D01</i>	<i>D02</i>	<i>D03</i>	<i>D04</i>	<i>D05</i>	<i>D06</i>	<i>D07</i>	<i>D08</i>	<i>D09</i>	<i>D10</i>	<i>D11</i>
GWLo	SUB	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
OGWo	SUB	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PECo	SUB	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PERo	SUB	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SUEo	SUB	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ZMGo	SUB	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
GWT	THR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
JCT	THR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes
LWTo	THR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LIT	THR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LITo	THR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
WLK	THR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
WLKo	THR	Yes	No	No	No	No	No	Yes	No	No	No	No	No
KRZ	PCA	No	No	No	No	No	No	No	No	Yes	No	Yes	No
KRZo	PCA	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes
PCT	PCA	No	Yes	No	No	No	No	No	No	Yes	Yes	No	No
PCTo	PCA	No	Yes	Yes	No	No	No	Yes	No	No	Yes	No	Yes

continued on next page

Continuation													
WTC		D00	D01	D02	D03	D04	D05	D06	D07	D08	D09	D10	D11
PTT	PCA	No	Yes	No	No	No	No	Yes	No	No	No	No	No
PXE	PCA	No	No	Yes	No	No	No	No	No	Yes	No	No	No
PXEO	PCA	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	Yes
ERP	LDR	No	No	Yes	No	No	No	No	No	No	No	No	No
ERPO	LDR	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
KIR	LDR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LND	LDR	No	Yes	Yes	No	No	No	Yes	No	Yes	No	Yes	No
PTSO	LDR	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
CAP	OPT	No	No	No	No	No	No	No	No	No	No	No	No
CAPo	OPT	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
CKM	OPT	No	No	No	No	No	No	No	No	No	No	No	No
CKMo	OPT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
NNWo	OPT	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PXK	OPT	Yes	No	No	No	No	Yes	Yes	No	No	Yes	Yes	Yes
PXKo	OPT	No	Yes	Yes	No	No	No	Yes	No	Yes	Yes	Yes	Yes
SAN	OPT	No	No	No	No	No	No	No	No	No	No	No	No
SOM	OPT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
RAC	RAC	No	No	No	No	No	No	No	No	No	No	No	No
Yes		21	25	22	20	19	20	26	19	24	22	25	24
%	64%	60%	71%	63%	57%	54%	57%	74%	54%	69%	63%	71%	69%

4.5.4.5 Verification of the impact of the number of classes in the classification of CT

The intuition and previous results suggest that together with the growth of the number of classes grows the dependence among classifications and the type of the weather. The hypothesis was, that the coefficient of correlation RS fulfilled the dependence $RS^{09} < RS^{18} < RS^{27}$ on the predominant area of the domain. An analysis of the dependence of the power of the correlation relationship depending on the number of classes was carried out. As the measure of the fulfillment of this dependence one accepted the difference of the volume under the planes determined by RS^{09} , RS^{18} , RS^{27} . The catalogue COST733CAT-2.0 contains 2122 cases of the existence of regular sequences 09–19–27.

The intuition and previous results suggest that together with the growth of the number of classes grows the dependence among classifications and the type of the weather. Hypothesis was that that the coefficient of correlation RS fulfilled the dependence $RS^{09} < RS^{18} < RS^{27}$ on the predominant area of the domain. One carried out the analysis of the dependence of the power of the correlation relationship depending on the number of classes. As the measure of the fulfillment of this dependence one accepted the difference of the volume under planes determined by RS^{09} , RS^{18} and RS^{27} . The catalogue COST733CAT-2.0 contains 2122 cases of the existence of regular sequences

09–19–27.

Table 4.18: The number of cases of the fulfillment of the established hypothesis.

<i>Modification of the number of classes</i>	<i>Unfulfilled dependency</i>	<i>Satisfied the relationship</i>
From 09 to 18 classes	18	2104
From 18 to 27 classes	87	2035
From 09 to 27 classes	8	2114

As can be seen from Tab. 4.18 the comparison RS^{09} and RS^{18} showed that the postulated hypothesis was fulfilled in 2104 cases. Negative cases concerned mainly temperatures (15/18) and happened for the classification CT: ERP, PCT, PTT, RAC. The comparison RS^{18} and RS^{27} showed that the postulated hypothesis was fulfilled in 2035 cases. Negative cases concerned mainly temperatures (57/87) and occurred for the classification CT: ERP, JTC, PCT, PTT, RAC. The comparison RS^{09} and RS^{27} showed that the postulated hypothesis was fulfilled in 2114 cases. Negative cases concerned mainly temperature (7/8) and occurred for the classification CT: ERP, PCT, PTT, RAC.

4.5.5 Final results - the recapitulation

Methods based on the analysis of principal components and optimization methods was chosen most often. None of the classification fulfilled the established criterion in the domain D00. Either none of the classification was chosen for the weather pattern connected with the precipitation in domains D09, D10, D11. The weaker criterion of the choice ($RS^{1stQu.} > 0.2$) allowed to select a number of the classification of types of the circulation for these domains. These domains seem to be more difficult at defining of the suitable system of the classification of types of the circulation. The optimization methods are most numerous and it seems that also most often fulfill the accepted criterion of the choice. The hypothesis about the stronger relationship among classifications CT with the greater number of classes and with types of the weather one can find confirmed. It turned out also that was not possible choosing of one classification CT which would be suitable for considered types of the weather and would show the best fit for all domains.

4.6 Climatological evaluation of circulation type classifications and precipitation in Norway/Fennoscandia

Author: Ole Einar Tveito

4.6.1 Introduction

The precipitation conditions in the Fennoscandian Peninsula highly depend on the atmospheric circulation. Another important factor is the orographic barrier along the western/Atlantic coast of the peninsula. The dominating atmospheric circulation types in this area are dominated by westerly winds and cyclones in the North Atlantic and the Norwegian Sea. (ref or example /Rasmus/Utsira vindrose?)

One of the issues evaluating circulation types is their ability to separate precipitation events sufficiently. Precipitation is a complicated element to examine as it is non-continuous both in time and space. In practice analysis of precipitation is a two component analysis: i) Analysis of precipitation occurrence and ii) analysis of precipitation sums. The second issue is further complicated by the skew distribution function of precipitation meaning that analysis tools based on the assumption of a Gaussian distribution cannot be directly applied.

The fundamental assumption of the evaluation presented here is that the classes resulting from a circulation type classification should show distinct variations with respect to both occurrence and with the precipitation amount distribution functions. The basic assumption and underlying idea of applying circulation type classifications for describing precipitation conditions is that the types describe different precipitation characteristics, both at single locations as well as spatial patterns.

In the evaluation described in the next chapters a Kolmogorov-Smirnov test is applied in order to evaluate if the in between type precipitation probability density functions are similar or different. Also the probability of precipitation occurrence is analysed, evaluating if the classifications produce types can distinguish between wet and dry days or represent dry and/or wet precipitation regimes.

4.6.2 Data

All precipitation series in the Norwegian Meteorological Institute climate database with more than ten years of observations within the ERA40 period (=COST733CLASS period) were analysed. The series cover the entire Norwegian mainland and the Norwegian Arctic (Svalbard and Jan Mayen). 950 precipitation series fulfilled the criteria having at least 10 years of observation within the time period covered by COST733CAT v.2.0.

Fig. 4.56 shows the Norwegian mainland stations analysed as well as the border of COST733 domain 02 that was defined as the main domain for Norway.

All 73 classifications in COST733CLASS version 1.2 and all 423 classifications included in the COST733CLASS version 2.0 (see Chapter 3) for COST domain D02 are evaluated. The abbreviations of the Classification are explained in Section 3.4.3.3 (pages 62f.)

Since COST733CAT 2.0 have many optional classifications with respect to input parameters, seasons and sequencing days the large dataset is split up in subsets to make the evaluation as “fair” as possible.



Figure 4.56: Norwegian mainland station network applied and the outline of domain D02.

In the next chapter all classifications methods are compared based on the 1-day, yearly classifications based on MSLP as input variable. Further are the effects of sequencing and additional input data evaluated for selected classifications. The results mainly refer to COST733CAT 2.0, but a few examples of cat 1.2 are also shown.

4.6.3 Precipitation occurrence

The types/classes in a circulation type classification should represent both very wet and very dry precipitation characteristics, and not all cluster close to a mean value. In this analysis standard deviation of the mean type precipitation occurrence frequencies within a classification is analysed. A large standard deviation of the between type standard deviations of precipitation occurrence mean values is there to prefer instead of classifications having a small standard deviation.

In this evaluation the probability for precipitation over a certain threshold (≥ 0.1 mm/day) was estimated for each type in each classification. The resulting “frequency bars” [as the example shown in Fig. 4.57 (a)] should show a relative variation. An example of a classification with very small variation in precipitation occurrence is shown in Fig. 4.57 (b).

One way to summarize such information for a precipitation station is by producing boxplots like the one presented in Fig. 4.58. Classification that does not discriminate wet and dry properties properly show very little spread and a narrow bar (example NNWC09) while methods separating wet and dry event like WLKC09 presents a wide bar.

Fig. 4.59 shows box plots of all the average station standard deviations of precipitation occurrence between types in each classification. The classifications shown are

..... 4.6 Evaluation of CT classifications in Norway

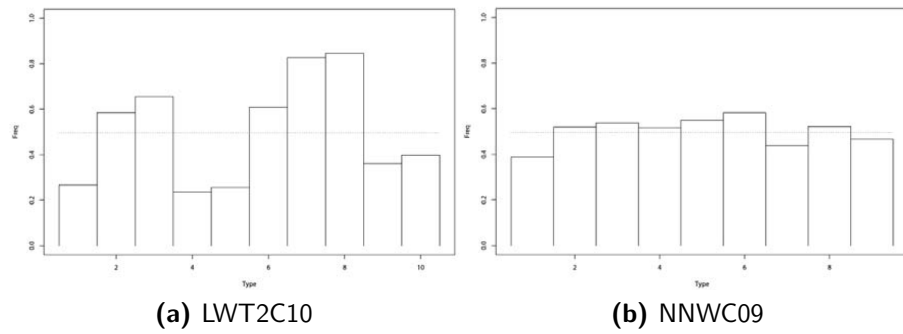


Figure 4.57: COST733CAT1.2 LWT2C10 type (left) and NNWC09 type (right) precipitation probabilities at the Norwegian precipitation station 18500 Bjørnholt. Standard deviation of the probabilities is 0.267 for the LWT2C10 classification and 0.169 for the NNWC09 classification.

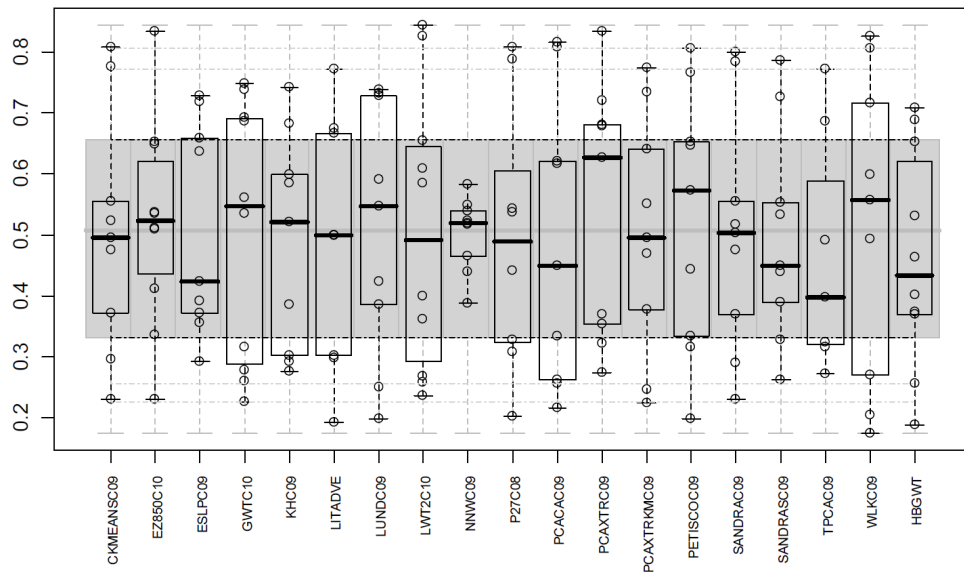


Figure 4.58: Boxplot showing the spread of type precipitation occurrence probabilities for the COST733CAT1.2 classifications with ≈ 9 types for station 18500 Bjørnholt. FIX X-AXIS LABELS, and save as EPS.. The grey-shadowed area represents the characteristics of all classes of all the classifications.

COST733CAT 2.0 classifications based on mean sea level pressure, annual types and sequence length of one day. A high standard deviation value is characterizing a better separation between wet and dry events. The colours in the figure indicate the methodological approaches of the classifications. It can be seen that the subjective catalogues (black colours) are not the best to separate precipitation occurrence.

The reason is rather obvious since these catalogues are developed for other regions than Western Fennoscandia, and therefore should not be expected to describe all circulation patterns having an important impact on precipitation conditions in the studied area. The red bars represent threshold based methods. Generally these methods show values above average, and LWTto10 show the highest standard deviation. It is also on of the classification in this category having less spread in standard deviation values. The next category of classifications methods are methods based on principal compo-

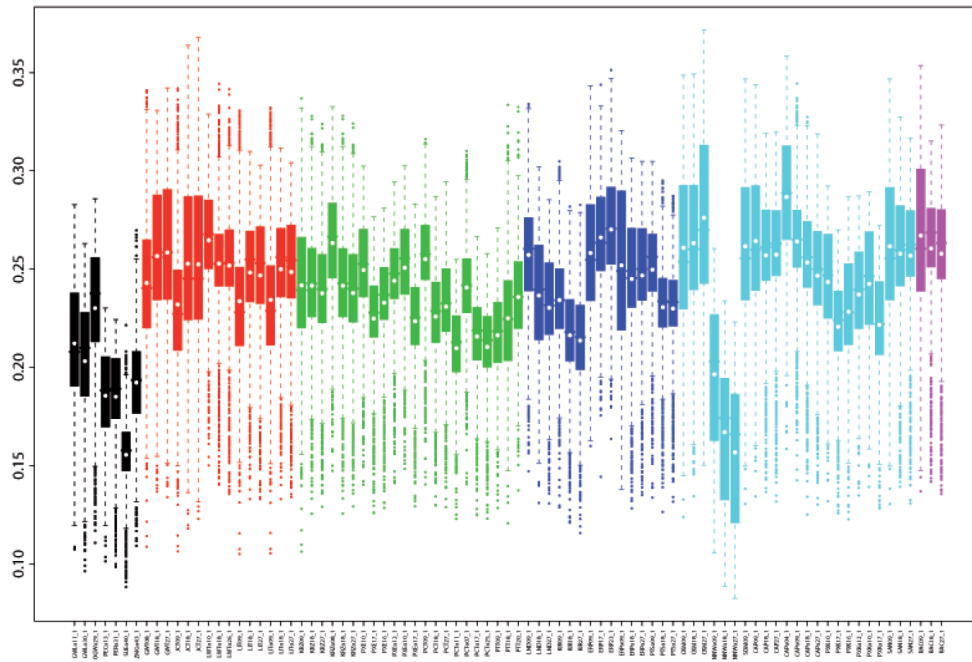


Figure 4.59: Boxplots of average standard deviation of precipitation occurrence of the circulation type classifications. (Black: Subjective methods, Red: Threshold methods, Green: PCA-based methods, Blue: Leader algorithms, Cyan: Optimisation algorithms, Purple: Randomized methods).

nents (PCA). In general this category shows average values except the original tmode PCA based classifications (PCTo) and the orthogonally rotated t-mode PCA classifications (PTT) that shows lower values. Among the leader algorithm classifications (blue colours) the Erpicum classifications shows values above average. The COST733 version of these classifications shows better scores than the original catalogues. The optimisation classifications (cyan color) have large variations in standard deviations of precipitation occurrences. The neural network classifications (NNW) show very low results, while the closely related self organizing maps method (SOM) show values well above average. This indicates that the optimisation algorithm is as well important as the classification principle itself. The k-means clustering (CKM), cluster analysis of PCA (CAP) and the SANDRA methods are all showing good performance. The random classifications (purple) also show scores above average.

Fig. 4.60 shows the classifications ranked with respect to the average standard deviation and Fig. 4.61 the ranking categorized by number of types in each classification. From Fig. 4.60 is can be seen that the average standard deviation of the classifications is slowly decreasing. The classification with the highest standard deviation is the CAPo04 classification containing only 4 types followed by the k-means (CKM) classification with 27 types. The subjective classifications and the NNW classifications are forming the group with lowest values indicating that they are not adaptable for this region. Fig. 4.61 shows the same ranking sorted by number of types. The general picture is that classifications with few types are preferable when describing precipitation occurrence. Exceptions are k-means cluster (CKM), Erpicum (ERP) and Gross Wetter Types (GWT) classifications where the higher number of types gives better score.

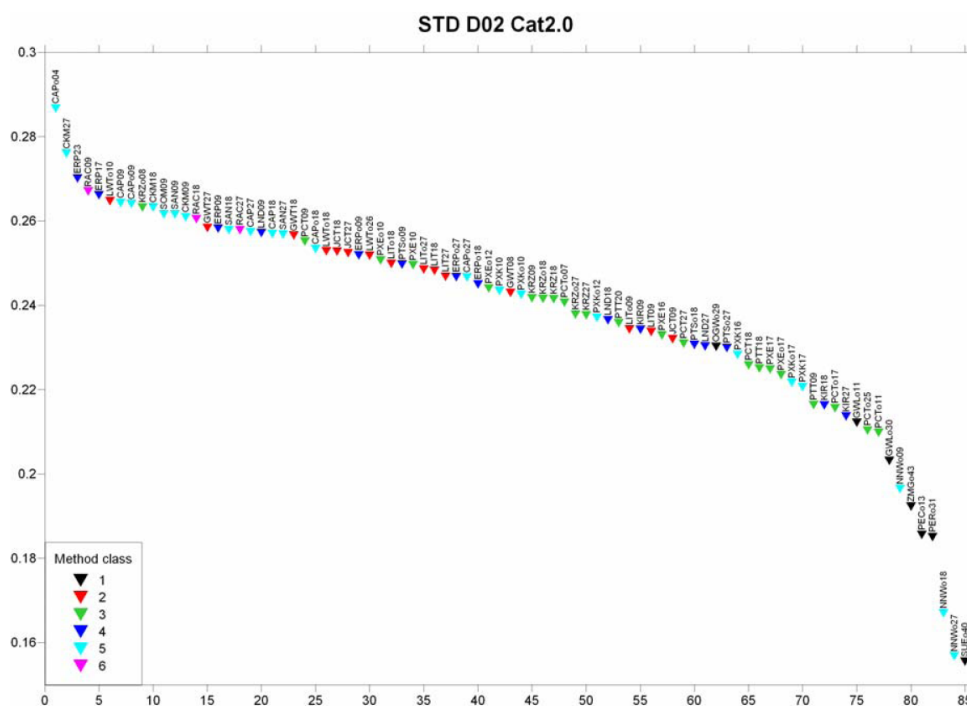


Figure 4.60: Ranking of classifications based on averaged standard deviation of precipitation frequencies. The colours represent method class.

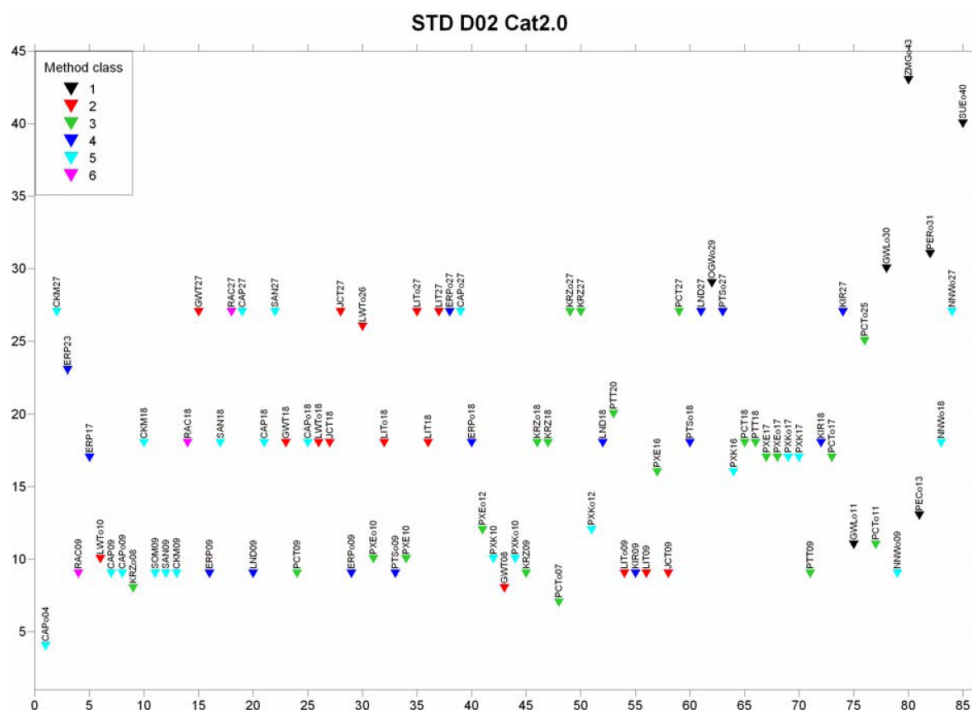


Figure 4.61: Ranking of classifications based on averaged standard deviation of precipitation frequencies sorted by number of types. The colours represent method class.

4.6.4 Precipitation distributions

A basic assumption in climatological evaluation of circulation classifications is that the frequency distributions of the response variables for the types produced by a classification are significantly different. In the evaluation described in this chapter the precipitation events over a certain threshold (≥ 0.1 mm/day) are fitted to a γ -distribution. The motivation for choosing the γ -distribution is that this distribution function is assumed to fit well to the highly skewed distribution of daily precipitation.

Evaluation is done by comparing

1. the type specific precipitation distribution functions of the classification with each other (hereafter called between)
2. type specific precipitation distribution functions with the distribution functions for all precipitation events regardless of the circulation types (hereafter called all).

A Kolmogorov-Smirnov test is applied to compare and detect significant similarities of the distribution functions. The analysis is carried out for single stations, and the resulting rank tables represent average statistics for all the stations applied.

Fig. 4.62 shows the fraction of significant differences between the type specific frequency distributions within the classifications. A higher number imply better separation between the classifications (TVEITO, 2010). It can be seen that most classifications have a quite good separation, and there is little variations between the different classification categories. Among the subjective classifications it is only GWLo11 and PECo13 that fail.

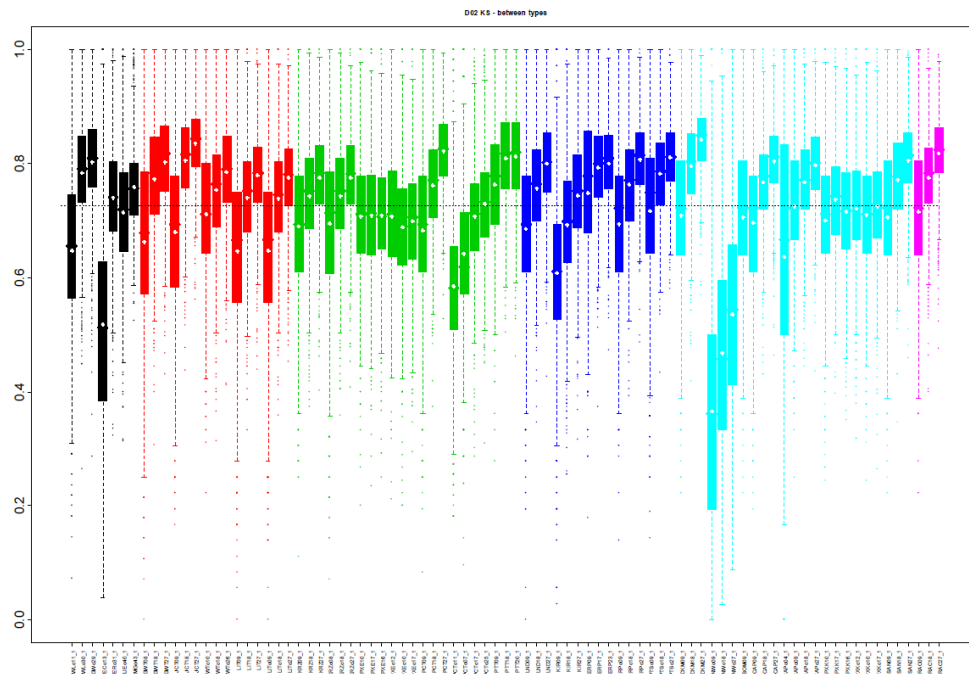


Figure 4.62: Boxplots of fraction of significant different type specific precipitation distributions within the classifications. The dashed line marks the mean value.

It is a clear tendency that classifications with few types show lower scores than classifications with many types. (Fig. 4.63). Threshold and leader algorithm methods (except

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Kirchofer, KIR) are generally performing well and slightly better than the other as group. Also cluster analysis based classifications are performing well, and it is the k-means cluster method that has highest score. These classifications also tend to have a smaller variation than the threshold and leader algorithms classifications. There is however small variations in the mean fraction for almost all classifications (Fig. 4.62 and 4.64). It is only a very few type classifications and the neural network classification that fails.

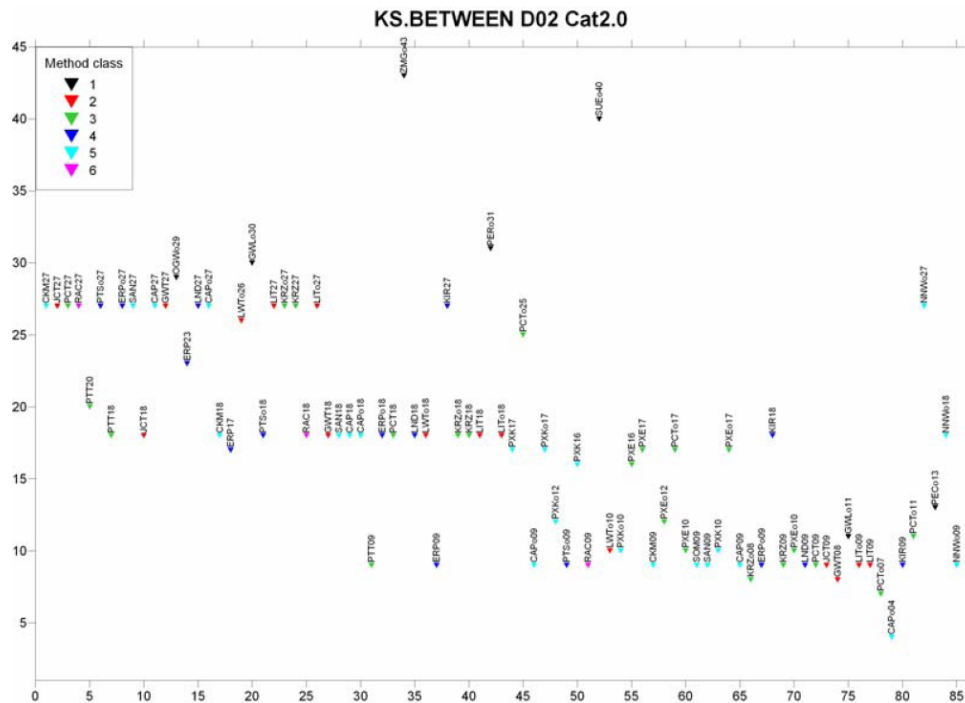


Figure 4.63: Ranking of classifications based on the fraction of significant different type specific precipitation distribution functions sorted by number of types. The colours represent method class.

When comparing the type specific precipitation frequency distribution functions with the distribution function of all precipitation events the results are a bit different. It is still the classifications with a high number of types that generally performs best.

From Fig. 4.65 it can be seen that the threshold based method generally produce high scores. But also in the cluster, leader and optimization categories many of the classifications perform equally well. Compared to the within classification comparison the variation width is larger when compared to the all event distribution. The “best” classification is the subjective based objective Grosswetterlagen classification with slightly higher value than a number of other classifications. The scores are rather similar and it cannot be decided which method is the best.

In Fig. 4.68 an attempt to give an overall ranking is given. This is based on a weighted average of the individual ranks of std, ks.all and ks.between where std has twice the weight as the other two. As seen from Fig. 4.68 six classifications are standing out as best. The best classification is CKM27. It is among the two best for ks.between and std, but has low performance for ks.all. The next one is CKM18, so it is quite obvious that the k-means cluster methods seems to a favourable approach for precipitation in Norway. The third best method is the randomcent classification with 27 types. Also the

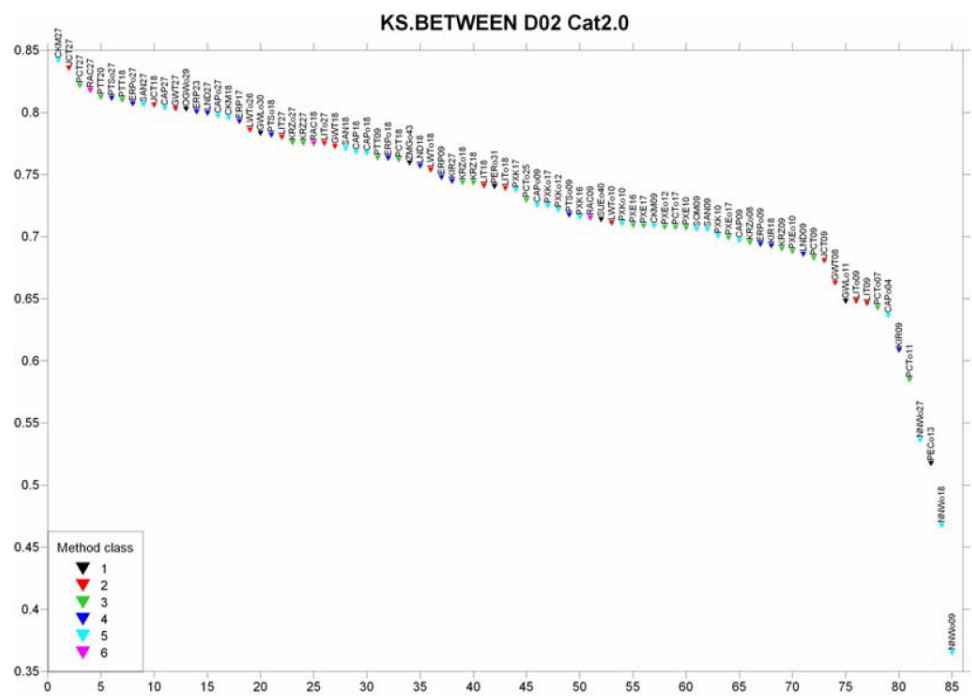


Figure 4.64: Ranking of classifications based on the fraction of significant different type specific precipitation distribution functions. The colours represent method class.

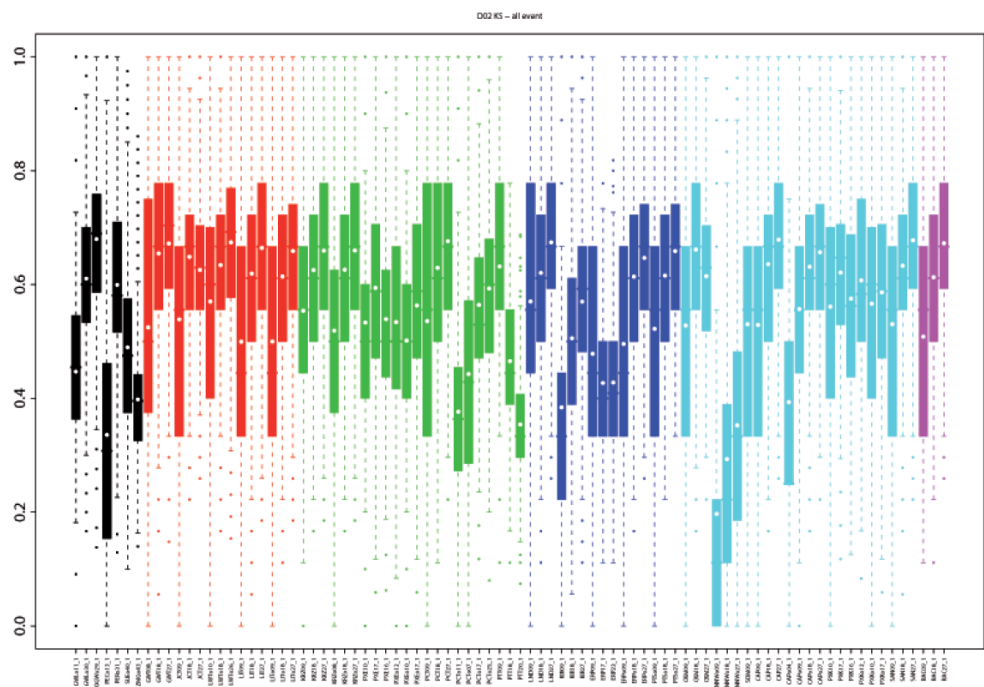


Figure 4.65: Boxplots of fraction of significant different type specific precipitation distributions with non classified frequency distribution function. The dashed line marks the mean value.

next three methods in the ranking contain 27 methods, so this seems to be the favourable number.

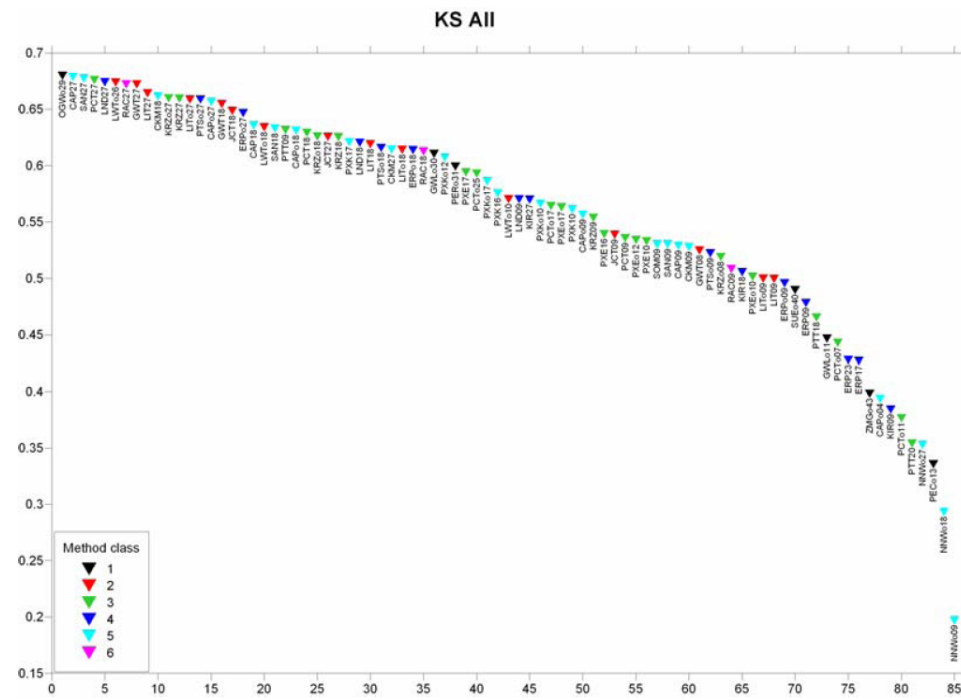


Figure 4.66: Ranking of classifications based on the fraction of significant different type specific precipitation with the non classified frequency distribution functions. The colours represent method class.

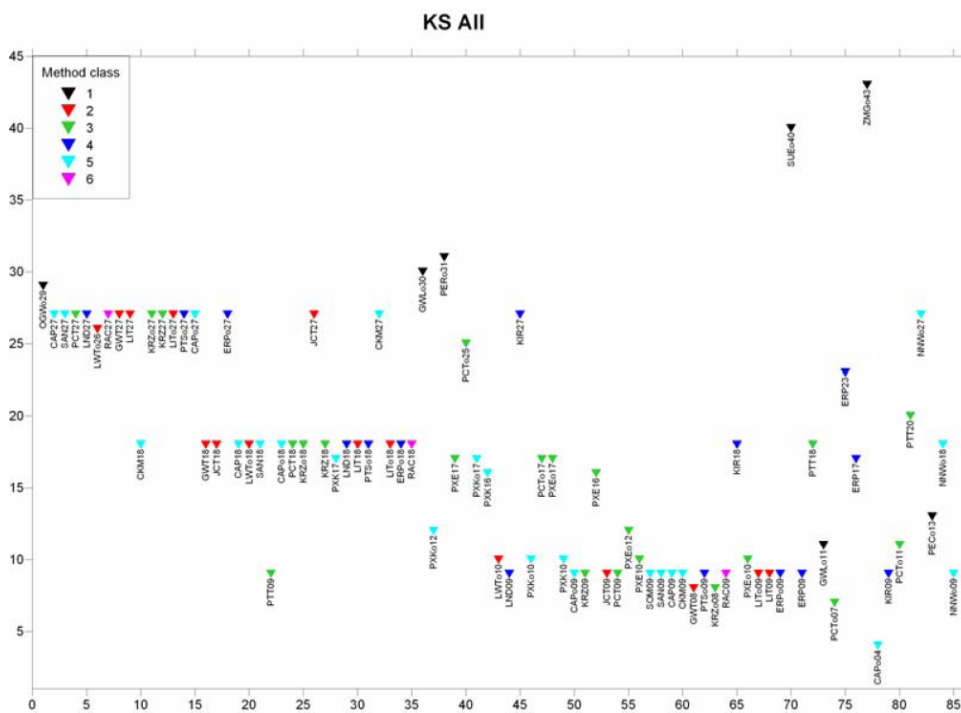


Figure 4.67: Ranking of classifications based on the fraction of significant different type specific precipitation with the non classified frequency distribution functions categorized by number of types. The colours represent method class.

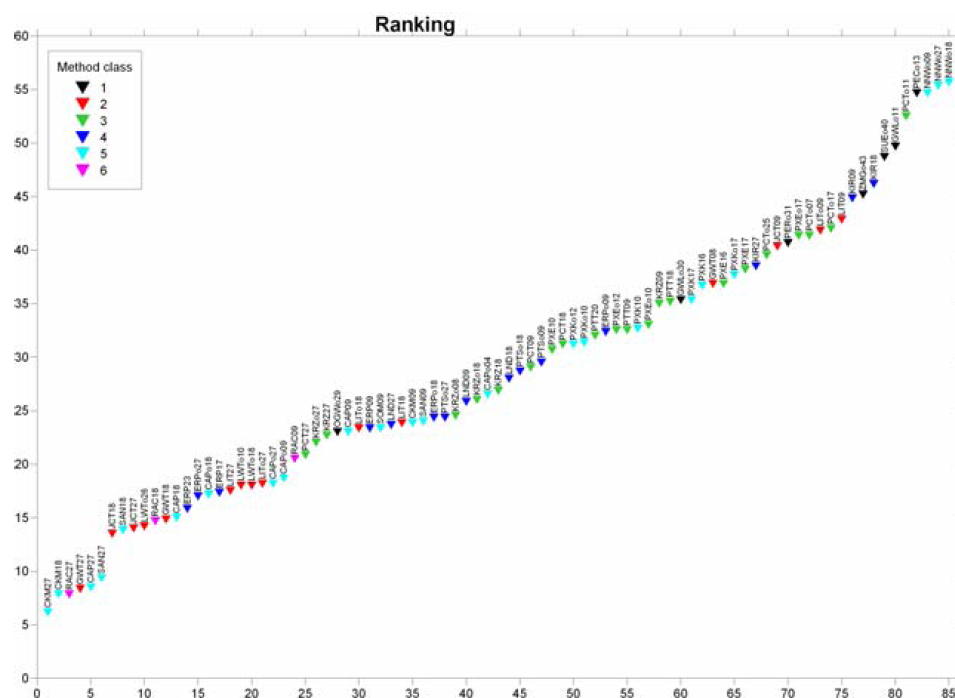


Figure 4.68: Overall ranking.

4.6.5 Other input variables

The validation presented so far is based on classifications using mean sea level pressure as input variable only. One of the recommendations from COST733 has been to include also other atmospheric variables in the classifications, and this feature is included for some of the classifications in COST733CAT 2.0.

In the following we are examining the effect of using additional input parameters to the CT classifications. Only classifications with ≈ 27 types are analysed since the results presented above indicates that this is the most favourable number of types.

For precipitation occurrence the standard deviation of precipitation occurrence between the types in the classification do not reveal a systematic improvement including additional input parameters (Fig. 4.69). Also when testing the significance of between type frequency distribution functions there is no evidence that more input parameters improve the classification. Single day classifications seems to be superior to the 4-day sequence classifications prepared in COST733CAT 2.0 (Fig. 4.71).

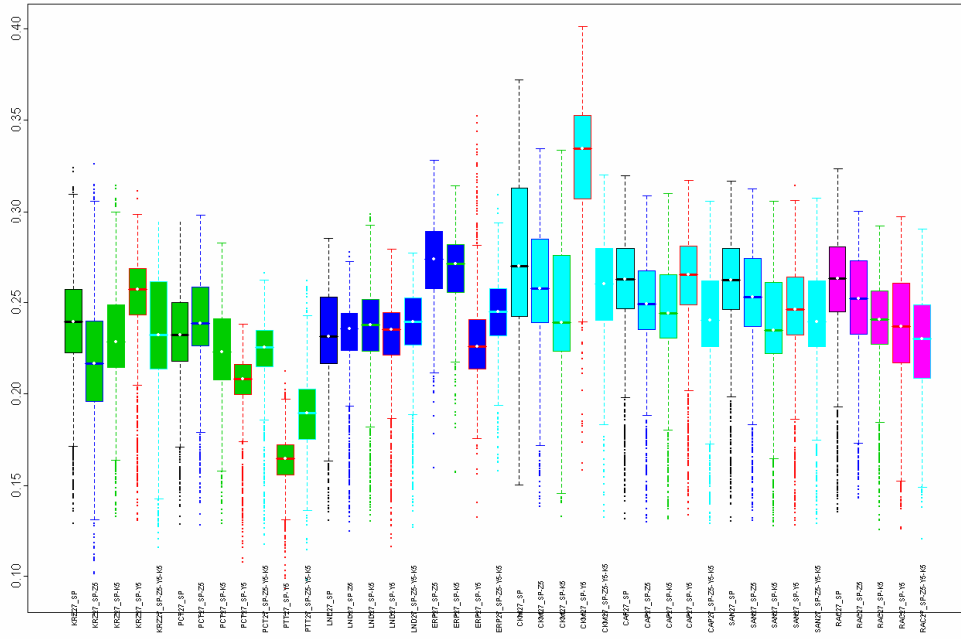


Figure 4.69: Boxplots of average standard deviation of precipitation occurrence of the circulation type classifications. The outline colours represent input variables (Black = MSLP, Red=MSLP + Vorticity of z500hPa, Green = MSLP + Thickness z850/500 hPa, Blue = MSLP + z500hPa, Cyan = MSLP + z500 + vorticity of z500 + thickness z850/z500).

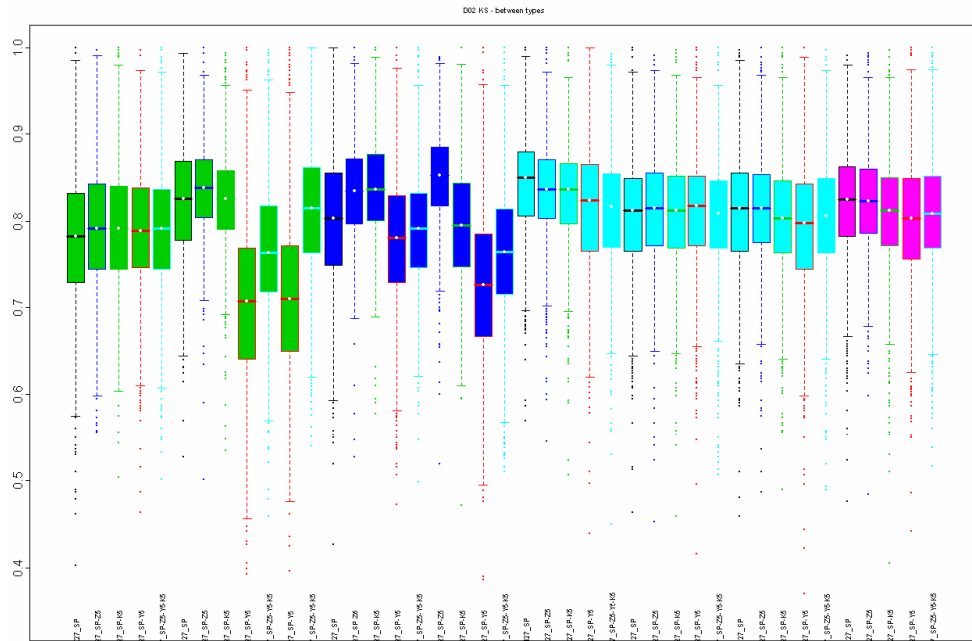


Figure 4.70: Boxplots of fraction of significant different type specific precipitation distributions within the classifications. The outline colours represent input variables (Black = MSLP, Red=MSLP + Vorticity of z500hPa, Green = MSLP + Thickness z850/500 hPa, Blue = MSLP + z500hPa, Cyan = MSLP + z500 + vorticity of z500 + thickness z850/z500).

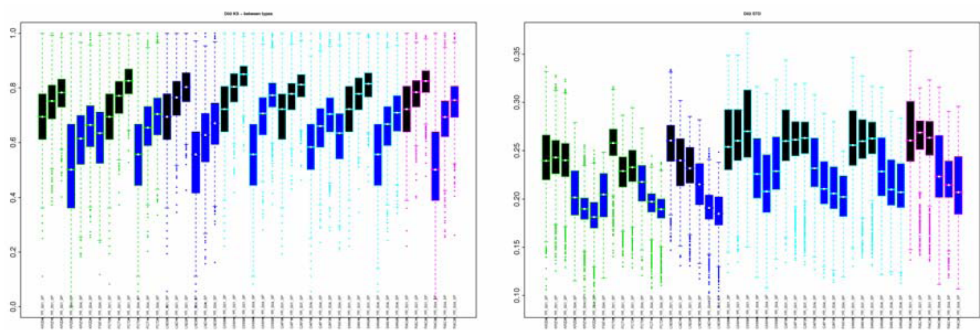


Figure 4.71: Boxplots of fraction of significant different type specific precipitation distributions within the classifications (Left) and of average standard deviation of precipitation occurrence of the circulation type classifications (right) for one (black) and four (blue) day sequences.

4.7 Subjective evaluation of the COST733 Catalogues

Authors: Pere Esteban, Javier Martin-Vide, Constanta Boroneant, Florinella Georgescu, Juhana Hyrkkänen, Massimiliano Pasqui, Rita Pongracz, Dimitar Nikolov, Arne Spekat and Ole Einar Tveito

4.7.1 Description of the method

The basic idea of the method is to evaluate the circulation type classifications from the climatologist background perspective, i.e, highlighting the coincidences and differences between the patterns obtained in the catalogues and the spatial patterns that the subjective expert knowledge considers as the main and necessary types to be identified and discriminated in a classification. Relevant circulation types (CT) in terms of, for example, frequency or meteorological behaviour “naturally” exist for the different domains (see example below for the Iberian Peninsula). Considering their characteristics, there is the possibility of their not being well represented by classifications mainly because of methodological limitations.

Using the COST733 catalogue provided by WG2 (version 1.2 <http://cost733.geo.uni-augsburg.de/cost733wiki/Cost733Classifications>), different domains and classifications were analysed by the WG3 participants from this expert knowledge point of view. Specifically, results for 9, 18 and 27 types were treated for the following methods: CKMEANS, EZ850, ESLP, GWT, KHC, LITTC, LUND, LWT, NNW, P27, PCACA, PCAXTR, PCAXTRKM, PETISCO, SANDRA, SANDRAS, PCAC27, WLKC28, HBGWL, HBGWT, OGWL, OGWLSLP, PECZELY, PERRET, SCHUEEPP and ZAMG.

Regarding the spatial patterns obtained in terms of Sea Level Pressure, 2m Temperature and Daily Precipitation for winter and summer (see 4.72 as example), the following questionnaire was completed (excel sheet format) by different participants of the action COST733:

- Is there any significant sea level pressure circulation pattern missing in your working domain?
No(1) Yes(0)
- Is there any significant circulation pattern related to precipitation in your working domain missing?
No(1) Yes(0)
- Is there any significant circulation pattern related to temperature in your working domain missing?
No(1) Yes(0)
- Are there any odd/inconsistent patterns?
No(1) Yes(0)

The domains finally analysed by WG3 have been D02, D05, D07, D08, D09, D10, with a total of 8 questionnaires completed.

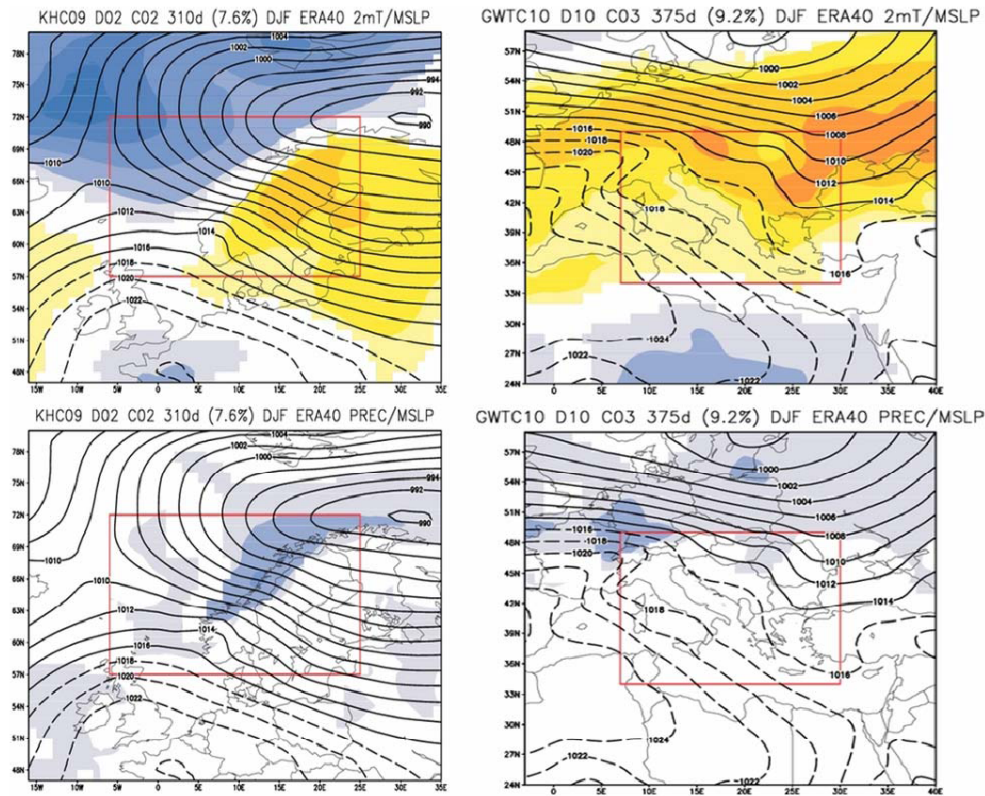


Figure 4.72: Example of the GRADS plots generated by WG2 and used for subjective evaluation. The caption shows information about the classification method, the number of types of the classification, domain, the cluster number, the days classified in the cluster, the percentage of days in the cluster, the season in terms of the corresponding months, data used, and variables represented.

4.7.2 An example of significant/relevant circulation types for the Iberian Peninsula area

In order to answer the questionnaire, a previous overview of the main features that characterize the studied area is necessary, establishing the basic types that have to appear in any classification of our area and the spatial structures that should be omitted and considered as odd patterns.

Analysing the results of existing classifications over Iberia and the knowledge derived from different climatologists, some conclusions related to the characteristics of the CT over the Iberian Peninsula area could be highlighted as examples when a Subjective Evaluation process is carried out:

1. It is important to distinguish different configurations of the Azores high because the Iberian Peninsula, Portugal and the northern area of Spain in particular, are very sensitive to small changes in wind direction and to the situation of the high's centre for producing precipitations and other weather phenomena.
2. The detection of less frequent patterns could be very important for the explanation of meteorological variables as precipitation, especially over the Mediterranean facade. Mediterranean lows, characterised by short lives and short spatial extent,

are probably the clearest example of this consideration. The methods and the spatial and temporal resolution of the grids should take care of this.

3. Patterns with low-pressure gradient over the Mediterranean, mainly in summer, are also important and should be considered as a potential group to obtain and analyse; patterns with similar spatial configurations but with clear differences on the spatial SLP gradient could be considered as different CT in the final classifications. In this way, introducing other atmospheric levels data to the analysis could also help in detecting these patterns when they are related to troughs at high levels.

4.7.3 An assessment of significant/relevant circulation types for Domain 07 (Central Europe)

A general assessment of a number of classification methods had been carried out using displays of meteorological fields, as exemplified in Fig. 4.72, for the Domain 07 (Central Europe) as well as tables with the relative frequencies of the classified patterns in yearly, seasonal and monthly aggregation. The questions from Subsection 4.7.1 have been addressed in Tab. 4.19 – occasionally the answer is *undecided* and is indicated by '0.5'; an example for the answers to the four questions above would be 1–1–0.5–0.5, i.e. y–y–u–u.

Table 4.19: The questionnaire from Subsection 4.7.1, answered for numerous methods and Domain 07 (Central Europe).

<i>Method</i>	<i>Answers</i>	<i>Method</i>	<i>Answers</i>
CEC	1–0.5–1–1	PETISCO	1–1–1–0.5
ESLPC10	0.5–0.5–0–0	SANDRA	1–0–0.5–0
ESLPC30	0.5–0.5–0–0	SANDRAS	1–0.5–0.5–0
EZ500C10	0.5–0.5–0–0	TPCAV	1–0.5–0.5–0
EZ500C30	0.5–0.5–0–0	TPCA07	0.5–0.5–0–0
GWT	0–0–1–1	WLKC733	1–1–0.5–0
LITADVE	1–0–0–0		
LITTC	1–0–0.5–0	HBGWL	1–1–0–0
LUND	1–1–0.5–0.5	OGWL	1–1–0–0.5
LWT2	1–0.5–0–0.5	PECZELY	1–1–1–1
NNW	1–0.5–0–0	PERRET	1–0.5–0.5–1
P27	1–1–0–0	SCHUEEPP	1–0.5–0.5–0.5
PCACA	1–0.5–0–0.5	ZAMG	1–0.5–0.5–1
PCAXTRKM	1–0.5–0.5–1		
PCAXTR	1–0.5–0.5–1		

Below Tab. 4.19 are comments and notes, if necessary, e.g. concerning the number of classes, the seasonality of the frequencies if the behaviour encountered was different when Domain 07 or Domain 00 was considered. Attention is given to the number of

classes used by the method and the kind of frequency distribution across the classes. Furthermore,

Note: The information below is rooted in a presentation at a WG3 Meeting in Barcelona and reflects the cat1.0 versions of the methods as of spring 2008. It should be acknowledged that some methods were improved in later stages of the COST Action, partly due to the findings of WG3. As part of Section 5.3.2, a subjective evaluation of some COST733CAT2.0 classifications is given in Tab. 5.14 on page 275.

Remarks – Objective Methods

4.7.3.1 CEC

This method has its particularities, since it classifies the patterns season-wise, so there are 4×10 classes. CEC does not produce a class that dominates the others; occasionally there are rather low relative frequencies in individual months, but for any class the count is well above 200 cases for the seasons.

4.7.3.2 ESLPC10

This method generates 10 classes. The full amount of classes occurs mainly in winter, whereas, particularly in summer, ESLPC10 orders the days into fewer classes. It is also noteworthy that the first class tends to dominate strongly, whereas the relative frequencies of classes 7–10 are comparably small or (outside of winter) often unoccupied. It may be surmised that fewer classes, e.g., on the order of seven) might be sufficient for this method.

4.7.3.3 ESLPC30

This is a variant of ESLPC10 which allows for more classes. Some features, e.g., dominating first class, the number of unoccupied classes in summer are also similar to ESLPC10. In this light perhaps a reduction to 10 classes may be solution.

4.7.3.4 EZ500C10 and EZ500C30

This a variant of ESLPC10/ESLPC30 which use 500 hPa information instead of sea level pressure (SLP) fields. As in their SLP relatives, a dominating class occurs. The effect of unoccupied classes in summer conditions, the situation could be improved somewhat, yet a condensation to 7 (EZ500C10), or 12 (EZ500C30) classes might be considered.

4.7.3.5 GWT

This method produces 18 classes. It is rather well balanced in terms of seasonality and relative frequency, i.e., the classes are occurring throughout the entire year, yet the counts can be down to <10 for some summer months. There is no single big dominating class, but a co-existence of several rather large classes. It should be noted that the seasonality is less well exhibited in the large Domain 00.

4.7.3.6 LITADVE

This method uses 9 classes. The distribution of the relative frequency is rather even, meaning that all classes appear with about the same frequency, a feature rarely in other methods. Therefore no big dominating class can be found. Furthermore all classes are well present in all seasons.

4.7.3.7 LITTC

Here, 27 classes are produced. The distribution of the relative frequency is not as even as in LITADVE, but there is no big dominating class in LITTC. Even though there are 27 classes in it, no individual class falls below a count of 25.

4.7.3.8 LUND

This classification uses 10 classes. If seasons are considered these classes all occur throughout the whole year, yet, for individual months the counts can be very low, nearly zero. There is no big dominating class. Note: The seasonality is well developed in Domain 07 but rather faintly visible in the large Domain 00.

4.7.3.9 LWT2

There are 26 classes in LWT2. As in LUND all classes occur throughout the whole year and the count is rather low in individual months. There is no big dominating class. Note: As with LUND, the seasonality is well developed in Domain 07 but rather faintly visible in the large Domain 00.

4.7.3.10 NNW

This method uses 20 classes. The seasonality is well exhibited and there is a tendency to have unoccupied classes, particularly in summer. There are two large dominator classes. Note: As with LUND or LWT2, the seasonality is well developed in Domain 07 but rather faintly visible in the large Domain 00.

4.7.3.11 P27

A classification into 27 classes is used. The noteworthy features of P27 are similar to those of LITADVE.

4.7.3.12 PCACA

This classification tends to produce different number of classes for different-size domains which are on the order of 12. In individual months the counts can be down to about 10, but the seasonality is well present, i.e., the frequency distributions are looking differently in the seasons. There is no big dominator class.

4.7.3.13 PCAXTRKM and PCAXTR

As with PCACA the number of classes varies with the Domains and is on the order of 15. The seasons are well captured in the patterns' frequency distributions. There is no

unoccupied class in the seasons but if single months are considered the counts can be down to about 10. There is no big dominating class. Note: The seasonality is well developed in Domain 07 but rather faintly visible in the large Domain 00.

4.7.3.14 PETISCO

This method produces 14 patterns. It has a well balanced behaviour in the relative frequency for the occurrence in the whole year. A seasonal behaviour can also be detected – for individual months in summer the count can be as low as 10. PETISCO produces two large dominating classes. Note: The seasonality is well developed in Domain 07 but rather faintly visible in the large Domain 00.

4.7.3.15 SANDRA

This method makes use of 18 classes. Its seasonality is very well exhibited, e.g. summer and winter regimes are reflected in different-looking frequency distributions of the 18 classes. In summer conditions, there is a rather high number of empty classes – six of the 18 SANDRA-patterns would be sufficient to describe the summer conditions. There is not one but there are four rather large dominating classes.

4.7.3.16 SANDRAS

SANDRAS is characterized by using 30 classes. The seasonality is, comparable to SANDRA, very well exhibited. If a monthly breakdown is applied, it occurs that individual classes vary largely from month to month. Even though the overall number of classes is larger as with SANDRA, about 20 classes would be needed to describe winter conditions and about 8 classes would be sufficient in summer. Yet, apparently all 30 classes are needed, because they have their individual "weights" during parts of the year. There is no single big dominating class.

4.7.3.17 TPCAV and TPCA07

This classification is also using a different number of classes – 12 in Domain 00 and 9 in Domain 07 (7 for TPCA07). If the whole year is considered, the frequency distribution does not show a single dominating class and the the distribution is overall rather even. There are no unoccupied classes when seasons or months are considered and the relative frequency tends to stay above 60, even in monthly resolution. Note: With TPCAV and TPCA07 there is more seasonality and a tendency to exhibit a dominating class in Domain 07 whereas in Domain 00 these properties are less well visible.

4.7.3.18 WLKC733

This classification produces the largest number of classes among the objective methods: 40. There are many unoccupied classes when monthly and seasonal aggregation is considered. Some of the classes are very infrequent even for the year. A reduction to about 20 classes could prevent these occurrences. There is one big dominating class in Domain 00 and three in Domain 07.

Remarks – Subjective Methods

There is no point in looking at specific features of the subjective methods concerning Domain 00 or 07 since they are developed on just one domain.

4.7.3.19 HBGWL

This classification is built upon 29 classes. There are sparsely occupied and even a few unoccupied classes for some seasons. The seasonality is well present, i.e., the frequency distributions are varying over the year. It is noteworthy that there is a dominating class (Western Type) which is dominant in all seasons.

4.7.3.20 OGWL

This classification is also built upon 29 classes. The distribution over the year is more even than in HBGWL (between 300 and 1300 members in the individual classes). On a monthly scale this distribution is rather uneven (between ≈ 10 and 150 cases), yet the classes are always occupied, albeit with an occasional membership below 10 cases. There are two dominant classes. Seasonality is variable among the classes. In contrast to HBGWL the frequent classes exhibit a more prominent seasonality.

4.7.3.21 Peczely

The classification uses 13 classes. It is not entirely conditioned on Domain 07. The Peczely classification is balanced in many respects: The number of members in the classes are rather similar – this holds true for the full year and the individual seasons. All classes are well occupied. There is not one dominating class but four are slightly bigger than the rest.

4.7.3.22 Perret

There are 31 classes in Perret. If annual frequencies are considered, the balance is rather well (160–1500 members). If monthly frequencies are considered the membership is between 0 and 200. There are five “dominator” classes and the seasonality is slightly visible.

4.7.3.23 Schüepp

This classification uses 40 classes. The annual frequencies are between 5 and 1100, thus a dissolution of a few very small classes might be worthwhile considering. The seasonality is visible in some, but not all classes. If monthly frequencies are considered, the classes have between 0 and 160 members, with a lot of empty classes and numerous classes with below 10 members. There are four large classes, which, strangely and different from other classifications have their maximum in summer.

4.7.3.24 ZAMG

This classification has the highest number of classes of all in the COST Action pool: 43. The annual frequencies are between 9 and 2100; there are about 15 very small classes which, as in Schüepp might be candidates for dissolution. Monthly frequencies

are between 0 and 270; there are numerous classes which are empty or have frequencies below 10. There is one “dominator” class with over 2000 cases (annually) and four classes with over 1000 cases. All large classes have, oddly, but similar to Schüepp, their maximum in summer. Large classes have a better developed seasonality.

Observations from the Domain 07 comparison

These observations stand out from the above subjective comparison that encompasses a multitude of classification methods in Domain 07:

- When comparing the frequency behaviour in Domains 00 and 07 it appears as if there would be a better seasonality in many methods when being conditioned to the *smaller* domain.
- Circulation classes that identify the (in Hess/Brezowsky terminology) *Westerly Type* are rather dominant. This domination appears to be better identified in many methods when the conditioning region is *not as large as Domain00*.
- Some classifications that use a large number of classes have representativity problems, i.e., some of their classes are “on the verge of extinction”.

4.7.4 Conclusions – Subjective evaluation of the COST733 Catalogues

The small number of questionnaires completed does not allow us to obtain a solid conclusion about the quality of the classifications. Moreover, it is also difficult to reach a clear conclusion because the questionnaire itself is a tool that does not “objectivize” enough the different subjective results coming from different analysts and domains. Looking at the results, it seems that there are significant differences on the subjective analysis criteria used due to the different experience and personal background of the WG3 participants. Despite this, the work done could be considered useful to highlight some general ideas, but does not allow detailed conclusions to be extracted in terms of methods, groups of methods, variable, or geographical variability.

In this way, is clearly observable that many methods are good, i.e., the quality of the classifications is similarly good between methods and few classifications are detected as “bad” ones. What is mainly relevant are the low scores generally obtained by NNW (Neural Networks), something related to the non ability of obtaining converged results with this method in this version 1.2 of the catalogue. As a good approximation, the average score of the classifications is 6–7 over a maximum of 8.

Considering the number of types, better results are obtained for 18–27 types than for 9, and are slightly better for 27.

Seasonally, better results are obtained for winter, but again with small differences in comparison with the summer results.

Finally, concerning the subjective classifications, good results are obtained for D07, where the majority of these classifications are more or less focused, while scores obtained in other geographical domains diminish in quality.

Working Group 4: Testing methods for various applications

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The primary aim of Working Group 4 (WG4), whose work is reported in this chapter, was to evaluate the applicability of the circulation type classification schemes already existing or developed within the action. Its remit sits within the overall COST733 following objectives:

- To identify a set of useful applications of circulation types classifications;
- to analyse the strengths and weaknesses of the methods for different applications.

These overall aims were complemented by WG4 specific objectives:

- Selection of dedicated applications (using results from WG1);
- collection/development of application software;
- performance of the selected applications using available circulation type data (from WG2);

- intercomparison of the application results as results of different methods;
- final assessment of the results and uncertainties;
- presentation and release of results to the other WGs and external scientific community;
- recommend specifications for a new (common) method

WG4 investigated the usefulness of circulation type classifications on a wide range of applications related to scientific domains from synoptic meteorology and climate, to environmental areas such as air quality and forest fires, to extreme events such as flood, drought, avalanches and extreme weather. A total of 31 different case studies were finalized and reported here, involving research scientists from 15 countries, and combining a total of approximately 50 authors. The challenge of WG4 was to evaluate each application in a coherent and consistent manner, so that general conclusions could emerge.

Because of the range of applications considered by WG4, the task related to the “Collection/development of application software” was identified as not to be feasible as different applications approach the quantification of circulation-environment links from a different point of view. Note, however, the COST733CLASS software developed in WG2 (see Section 3.4) includes a range of functionalities that have been implemented based on feedback from WG4 (e.g. multiple variables as input) and a range of evaluation indices were developed in WG3 (see Chapter 4).

In order to address its objectives, WG4 was divided into five subgroups:

- Climatology (Section 5.1),
- air quality (Section 5.2),
- extremes (including meteorological and resulting from impact; Section 5.3),
- forest fires (Section 5.4),
- others applications (Section 5.5).

Each sub-group was established to assess advantages and disadvantages of different classification methods for different applications, and if possible, to provide final recommendations for circulation types classifications tailored for specific applications. An overall schematic of the spatial domain considered for the studies of each subgroup is given in Fig. 5.1.

Where possible, the analyses evaluated systematically the benefits of the following options associated with circulation type schemes:

- *Family of algorithms*: Following the work by WG2, the classification methods were assessed according to five different groups, summarised by a 3-letter acronym: SUBjective, THReshold, PCA, LeaDeR, and OPTimization.
- *Domain size*: Each catalogue was produced from input data of different geographic extent, covering small areas of Europe to the whole of Europe.
- *Number of classes*: Objective catalogues were produced with as close as 9, 18 and 27 number of types (or classes).

- *Input variables*: COST733CAT v2.0 includes catalogues defined with single or multiple input data.
- *Seasonal*: COST733CAT v2.0 includes catalogues with types defined annually, or independently for each 3-month season.
- *Sequencing*: COST733CAT v2.0 includes catalogues in which types are associated to a single daily pressure fields only and types based on whole sequences of successive daily pressure fields (e.g. 4 days).

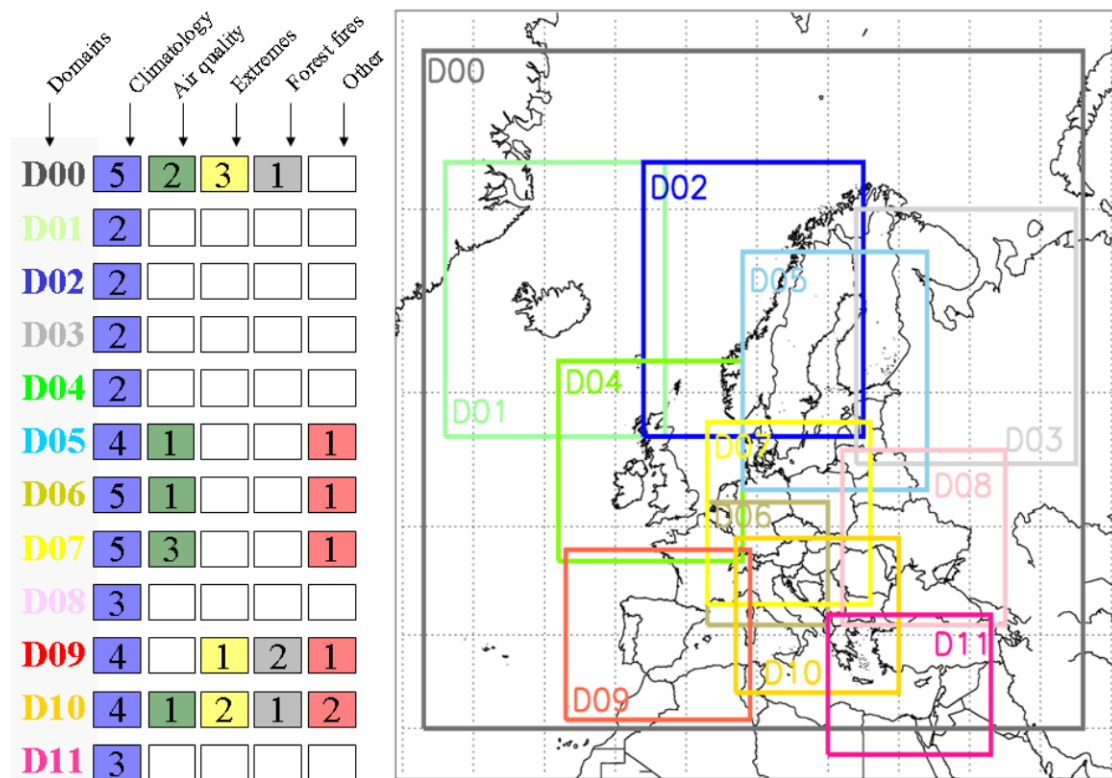


Figure 5.1: Number of case study considering the different domain definition of the COST733 catalogues regrouped by subgroup.

Note that there is some overlap with the activities of Working Group 3, in particular on the assessment of synoptic/surface meteorological variables (precipitation, temperature...). Where relevant, the evaluation methodologies developed by WG3 (see Chapter 4) to assess the performance of the circulation type classifications are used while more specific metrics are also used when more appropriate to the specificities of some applications.

This chapter reports the work of all sub-groups in five sections, each section concluding with a general summary of results obtained within the sub-group. The chapter ends with some general conclusions aiming to extract/point out any emerging general recommendation suggested by the 31 case studies.

5.1 Applications in Climatology

Climatology is an atmospheric science that studies climatic variability and trends at various time- and spatial scales. Basic climatic elements comprise air temperature, precipitation, sunshine duration, humidity, cloudiness, wind speed, etc. In this section we provide case studies that can be viewed as “purely climatological”, while several other climatology-related applications appear in the other sections of this chapter. Also, the study of extreme events is reserved to a special section.

Recent anthropogenic climate change is one of the most urgent environmental challenges that already threatens our civilization – and will do so even more in the future. Shift of seasons, changes of regional precipitation patterns and runoff, melting of glaciers and ice sheets, and rising sea level are just a few examples of the consequences of global warming. Even though natural climatic shifts similar to or greater than the recent one took place many times in the geological past, this is probably the fastest global change in the history of mankind. One of the ways to describe and understand recent climatic trends is through the study of atmospheric circulation and its changes.

In synoptic-climatological research, the desired approach is to study closely each circulation type and its physical properties – this is, however, lengthy or even impossible when dealing with many parallel circulation classifications. Hence the classical synoptic-climatological approach is usually condensed into a purely statistical one, without taking into account the underlying dynamical processes. Otherwise a selection of few classifications has to be done prior to the synoptic-climatological analysis itself. The selection of the most appropriate classification(s) is, however, neither easy nor straightforward, as was already shown in the results of WG3.

The main objectives of the “Climatology” subgroup of WG4 include:

- Comparison of different circulation classifications according to their ability to represent the variability of climatological elements or derived circulation/teleconnection indices (case studies in Subsections 5.1.1 to 5.1.3 and 5.1.5 to 5.1.6).
- Assessment of long-term changes (trends or regime shifts) in the frequency and persistence of circulation types, and identifying their possible causes (case studies in Subsections 5.1.7 to 5.1.9).
- Quantification of links between circulation changes and observed climatic trends (case study in Subsection 5.1.4).
- Attempts to enhance the performance of spatial interpolation of precipitation with the use of atmospheric circulation types (case study in Subsection 5.1.10).

5.1.1 Discriminant analysis as a tool for choosing appropriate circulation type classification: A case study using wind data of Slovenia

Author: Renato Bertalanič

5.1.1.1 Introduction

Climatological analyses mainly focus on measurements at the Earth's surface and circulation type classifications can be of great help. However, this requires finding the most appropriate classification, i.e. the one where connection between measurements and circulation types are good. This is difficult when hundreds of classifications are available, such as those defined for the COST733 Action.

Measured weather variables are mostly scaling variables, while circulation types are nominal variables. Discriminant analysis is a technique which links nominal and scaling variables. It is very similar to multivariate regression analysis but with the dependent variable being of nominal type. Discriminant analysis finds the linear relationship between simultaneously observed or measured variables in several points and circulation type. It can be used as classifier. Relative frequency of data correctly classified shows how good measured weather variables can predict a circulation type and vice versa: if relative frequency of data correctly classified is high we can expect that a circulation type can collectively describe chosen weather variables reasonably well. The bootstrap method was used to assess the statistical significance of the results. The methodology was applied to wind data over Slovenia, but could be used for any variable measured in several weather stations.

5.1.1.2 Data and Methods

The classifications considered are all 1692 classifications from COST733 catalogue version 2.0 defined over four different domains which cover Slovenia: Europe (D00), The Alps (D06), Central Europe (D07) and Balkans, SE Europe and Italy (D10).

The meteorological data contains daily average wind speed at 14 stations in Slovenia for the period 1997–2001. The stations cover Slovenia as much as possible to represent its climatic variability. As the time series is relatively short, a discriminant analysis and test of accuracy are performed on the same data. Ideally they should be performed on two independent sets of data, e. g. discriminant analysis on the first half of the data and test of accuracy on the other half of the data. Box-Cox transformation on wind data was done to achieve Gaussian distribution. The methodology followed several steps:

- Select wind measurements on a set of locations over the study area;
- Perform a transformation of variables to make them normally distributed. Box-Cox transformation was used for wind data. Homogeneity of variances which is the second of assumptions for discriminant analysis ([JOHNSON and WICHERN, 2007](#)) wasn't tested, but important final conclusions are dependent on this assumption;
- Select circulation type and appropriate domain;
- Perform a discriminant analysis using circulation type as dependent variable and measured data as independent variables;
- Use relative frequency of data correctly classified as a measure of agreement between measured data and circulation type classification. If possible the discriminant analysis and tests of correctly classified types should be performed on independent set of data (half of the data for discriminant analysis and other half for evaluation);

- Perform a bootstrap method to evaluate the statistical significance of the results. 500 resamples were used here.

5.1.1.3 Results

The greater part of the results is statistically significant ($p < 0.05$), while 324 (19%) classifications have statistically insignificant results. The results are in general very much dependent on the domain, the number of classes in the classification, the combination of input variables and sequencing. Generally a combination of additional input variables to sea level pressure (SP) perform better than the one based on SP only.

The highest scores are achieved for classification methods with smaller number of classes (Tab. 5.1), and hereafter classifications with the same number of classes are compared. The best results (between 40 and 55% of classes correctly classified) are achieved with classifications PTT, ERP, LND and PCT.

Table 5.1: First ten classifications with the highest relative frequency of correctly classified classes. N : Number of classes; $rf_{correct}$: Relative frequency of correctly classified classes; $boot$: Bootstrap p .

<i>Classification</i>	<i>N</i>	<i>rf_{correct}</i>	<i>boot</i>
PTT13_YR_S01_SP-K5_D10	13	0.57	0.002
PTT09_YR_S01_SP-K5_D10	9	0.56	0.002
PTT09_YR_S04_SP-K5_D10	9	0.56	0.002
PTT18_YR_S04_SP-K5_D10	18	0.55	0.002
PTT19_YR_S04_SP-K5_D10	19	0.55	0.002
PTT09_YR_S04_SP-Z5-Y5-K5_D00	9	0.53	0.002
ERP09_YR_S04_SP_D10	9	0.53	0.028
PTT12_YR_S04_SP-Z5-Y5-K5_D00	12	0.52	0.002
PTT09_YR_S01_SP-Z5_D10	9	0.52	0.002
PTT14_YR_S01_SP-Z5_D10	14	0.52	0.002

5.1.1.4 Summary and Conclusions

Relative frequency of classes correctly classified in discriminant analysis with wind data over Slovenia shows a dependency of the results with the domain of definition of the classification, domains D10 being the most appropriate for Slovenia (Fig 5.4). Not all results are statistically significant. Results also showed dependency on number of classes. Circulation types developed using additional input variables such as K5 (thickness between 500 hPa and 850 hPa geopotential height), Z5 (500 hPa geopotential height) and the combination SP-Z5-Y5-K5 (Y5 is vorticity of the 500 hPa GPH level) improve the results. Sequencing generally improves the results, whilst seasonality worsens it.

5.1.1.5 Recommendations

Box and whisker plots for the results are presented. The box's lower and upper hinge represent first and third quartile, the line in a box represents a median, whiskers are

shorten to 1.5 times the box length and outliers are marked with circles.

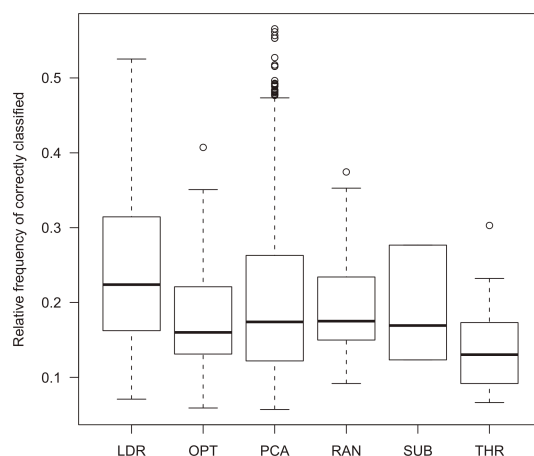


Figure 5.2: Relative frequency of correctly classified classes for family of algorithms.

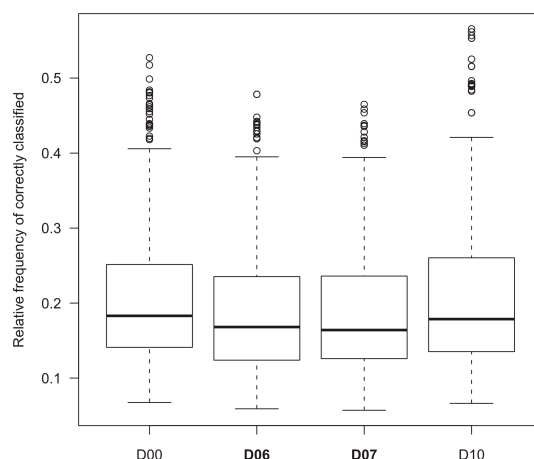


Figure 5.3: Relative frequency of correctly classified classes for different domains. Statistical significant difference in median between domain D00 and other domains is marked bold.

- **Family of algorithms**

The best results are achieved with LDR and PCA families of algorithms. The highest median has LDR group, OPT, PCA, RAN and SUB have similar median, while THR group has the lowest median (Fig. 5.2). Differences in median of SUB group and medians of other groups are statistically not significant due to small number of subjective classification. There are outliers in almost every group with very good results.

- **Domain size and locations**

The results over smaller domains are not necessary better than the results over large domain D00 (Fig. 5.3). Wilcoxon-Mann-Whitney 2-samples test shows statistical significant differences in medians of domain D00 and domains D06, D07. The use of domain D10 for wind analysis over Slovenia is preferred.

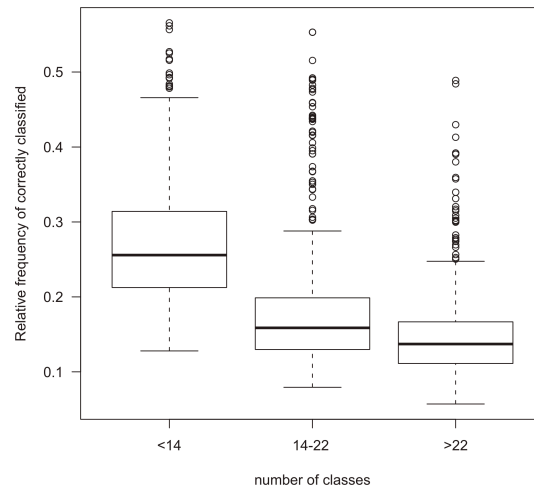


Figure 5.4: Relative frequency of correctly classified classes for number of classes.

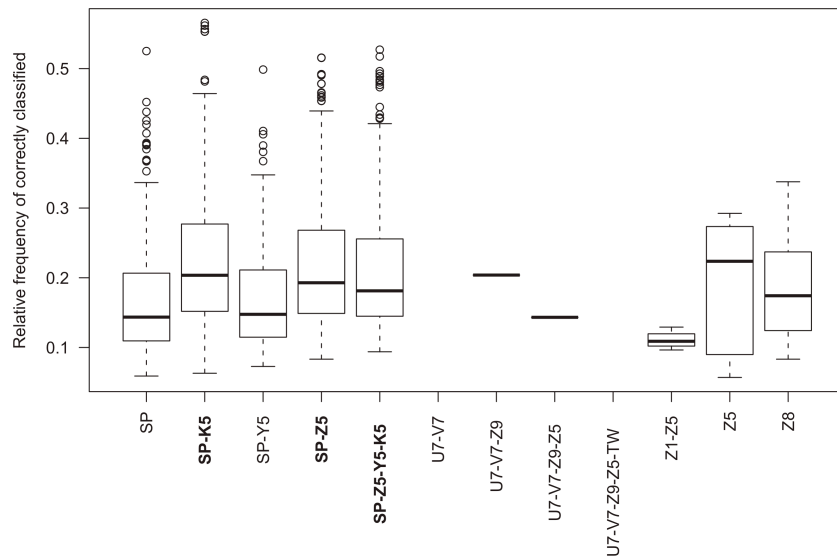


Figure 5.5: Relative frequency of correctly classified classes for different input variables. Statistical significant difference in median between classifications with only sea pressure input data and classifications with other input data is marked bold.

- **Number of classes**

The results are dependent on the number of classes; generally classifications with lower number of classes achieve better results (Fig. 5.4). Some classifications perform well for any number of classes (PTT, ERP, LND, PCT, CKM). The number of classes should relate to the application, with in general very variable phenomena requesting a larger number of classes.

- **Input variables**

Statistical significant differences in median from SP are marked with bold labels (Fig. 5.5). For wind data there is a meaningful difference in medians between SP and SP-K5, SPZ5, SP-Z5-Y5-K5, and no statistical significant difference for other. The inclusion of K5 (thickness between 500 hPa and 800 hPa geopotential

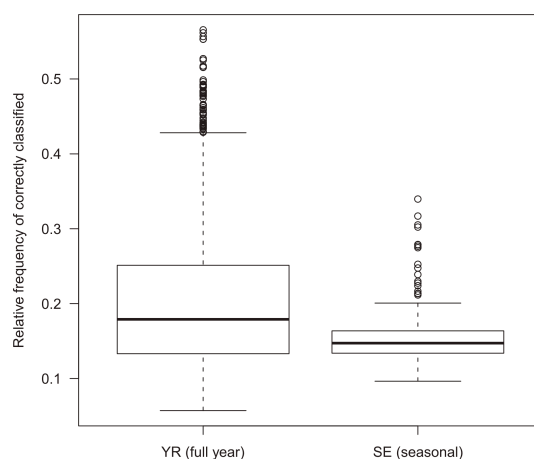


Figure 5.6: Relative frequency of correctly classified classes for yearly and seasonal classification.

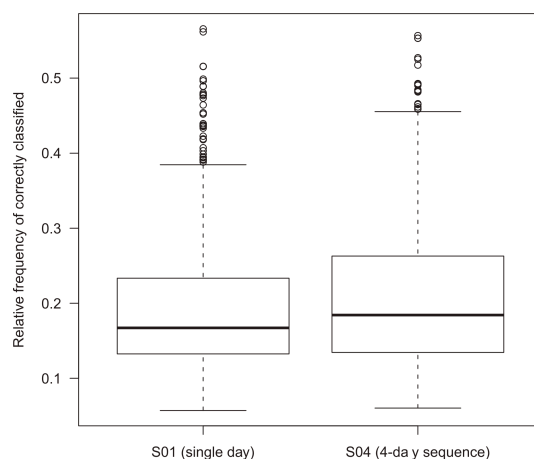


Figure 5.7: Relative frequency of types classified classes for one day and 4-day sequence of input data.

height), Z5 (500 hPa geopotential height) and Z5-Y5-K5 (vorticity of the 500 hPa level) improves the results. Other combinations cannot be proved to improve the results, some of them have too small number of cases. The use of multiple input variables is to be preferred over the use of only SLP as input variable.

- **Seasonal**

The difference in median between two groups is statistically significant, seasonality doesn't improve the results, it makes it worse (Fig. 5.6).

- **Sequencing**

The difference in median between two groups is statistically significant, but the best results are very similar (Fig. 5.7). Therefore it generally cannot be advised to use four day sequencing for wind data over Slovenia.

5.1.2 Circulation types versus NAO phases

Authors: Maria Asuncion Pastor and Maria Jesus Casado

5.1.2.1 Introduction

This study focuses on the relation between the large-scale synoptic circulation patterns and the North Atlantic Oscillation (NAO). The former aims at the identification of recurrent dynamic patterns (i.e. of sea level pressure) for a specific region, in which the derived set of circulation types (CT) provides a conceptual and simple frame where ideally, the specific weather situation of a particular day may be attributed to one of the CTs ([SCHIEMANN and FREI, 2010](#)). The latter phenomenon consists of a north-south dipole of anomaly with one centre located over Greenland and the other centre of opposite sign spanning the central latitudes of the North Atlantic between 35°N and 40°N. It has been shown that for the extra-tropical latitudes, it is the major winter climate mode of variability over the western part of the European Continent, explaining about one third of the inter-annual variability ([MARSHALL et al., 2001](#); [SCHWIERZ et al., 2006](#); [DEMUZERE et al., 2009a](#)). Both phases of NAO are associated with basin-wide changes in the intensity and location of the North Atlantic jet stream and storm track, and in large-scale modulations of the normal patterns of zonal and meridional heat and moisture transport ([MUNOZ-DÍAZ and RODRIGO, 2004](#); [HURRELL, 1995](#)), which in turn results in changes in temperature and precipitation patterns often extending from eastern North America to western and central Europe ([ROGERS and VAN LOON, 1979](#)).

At this stage, it is important to make a distinction between the concepts of CTs and modes of variability. Modes of variability are usually defined by means of Principal Component Analysis (PCA) and have been characterized in terms of both space-stationary and time fluctuating structures ([WALLACE and GUTZLER, 1981](#); [BARNSTON and LIVEZEY, 1987](#); [MONAHAN et al., 2000](#)). A circulation field can then be approximated by a linear combination of several modes of variability, which can be seen as main building blocks, of which the atmospheric circulation is composed ([HUTH et al., 2008](#)). In circulation type approach, however, we have a time series when each day is assigned to a given CT, being the spatial pattern of a CT, the average field of the days belonging to this CT.

The main interest of the study is in the joint use of two general circulation approaches: modes of variability and circulation classification methods, which usually are studied separately. Their relationship will allow us to establish a ranking using a large set of circulation classifications. The results might help to elucidate the relative merits of the most complete set of CT classifications based on the COST733CLASS software developed by [PHILIPP et al. \(2010\)](#).

5.1.2.2 Data and Methods

This research is mainly based on: a) a set of 53 classifications from COST733 catalogue version 1.2, and b) a subset of classifications of COST733 catalogue version 2.0. The domains selected are D00 and D09 and the period 1957–2002. Meteorological information is from the ECMWF–ERA40 dataset at 12h ([UPPALA et al., 2005](#)). Daily NAO index has been obtained from the Climate Prediction Center (CPC) derived using the Rotated Empirical Orthogonal Functions technique ([BARNSTON and LIVEZEY, 1987](#)).

Analysis focuses on the extended winter (December, January, February and March) as during that season, the atmosphere is more dynamically active and perturbations grow to their largest amplitudes, therefore exhibiting the largest variability over the extra-tropical regions (e.g. KUSHNIR and WALLACE, 1989; BLACKMON et al., 1984). In order to quantify the ability of circulation classification to discriminate the phases of NAO oscillation, χ^2 statistic has been chosen as a metric. As evaluation criteria, the higher the values of χ^2 , the better the discrimination power of the classification regarding NAO+ or NAO- phases. The daily NAO series was standardized and two phases were defined positive NAO (NAO+) and negative NAO (NAO-) corresponding to standardized values greater (lower) than 1.0 (-1.0) respectively. The χ^2 statistic was applied to each NAO phase and classification as

$$\chi^2 = \sum_{i=1}^I \left[\frac{(k_i - Np_i^{teor})^2}{Np_i^{teor}} \right] \quad (5.1)$$

where $p_i^{teor} = (n_i/N) * (K/N)$, k_i number of days of NAO+ (or NAO-) for each CT of a given classification, n_i number of days of a CT of a classification, K total number of days of NAO+ (or NAO-) for the period December 1957–March 2002, N total number of days of the period (5456 days) and I number of CTs for a given classification (approximately, 9, 18 or 27).

5.1.2.3 Results

This study focuses on the identification of those classifications which better discriminate the NAO phases as well as the impact of the number of CTs (C09 – 9 types, C18 – 18 types or C27 – 27 types). This is done for COST733CAT v1.2 and v2.0.

a) cost733cat version 1.2

The main results (PASTOR et al., 2009) can be summarized as follows:

- In C09 sub-catalogue (Fig. 5.8), classifications generally show a better discriminatory capacity for NAO- (higher χ^2 values for NAO- than for NAO+), except for ESLP, PCACA, LUND and TPCA. The best classifications for the NAO+ are amongst the optimization methods (OPT) and for NAO- OPT and Principal Component Analysis (PCA) methods. The worst classifications for discriminating both NAO phases are WLK from the threshold-based (THRES) methods and KH from the leader-algorithm (LEAD) methods.
- In C18 sub-catalogue (Fig. 5.9), χ^2 values are larger for NAO- than for NAO+ except for PCACA, and show higher discriminatory power than C09 classifications. The overall ranking of classification method is similar to that of C09.
- In C27 sub-catalogue (Fig. 5.10), χ^2 values are larger for NAO- than for NAO+ except for PCACA and KH. As in C09 and C18 sub-catalogues, the best classifications relates to the OPT methods for NAO+, while for NAO-, LUND from the leader algorithm (LEAD) methods was found best. Note the good performance of the subjective OGWL and OGWLSLP classifications, two-objectivized versions of Hess-Brezowsky catalogue. The worst-performing classifications are the same as those for the C09 and C18 sub-catalogues.

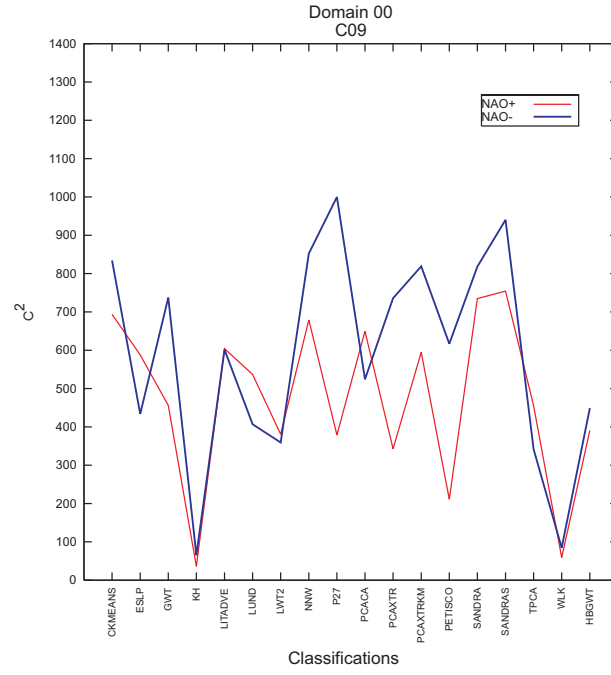


Figure 5.8: χ^2 values (axis label c^2) for NAO+ and NAO- for the classifications of C09 subcatalogue (COST733CAT version 1.2).

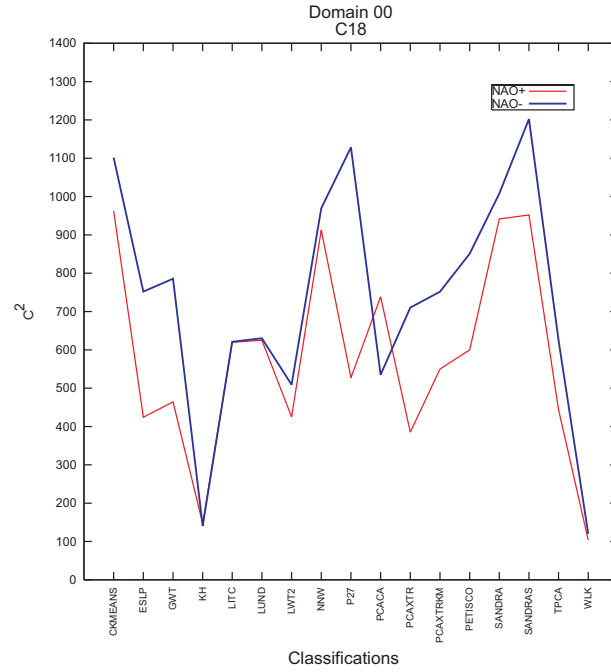


Figure 5.9: As in Fig.5.8, but for classifications of C18 subcatalogue (COST733CAT version 1.2).

b) cost733cat version 2

Here, the main emphasis is on the impact of dealing with different input variables, sequencing and seasonal classifications respectively. As a general rule, χ^2 values are larger for NAO- than for NAO+ (See Fig. 5.11–5.13). Broadly speaking, results confirm what

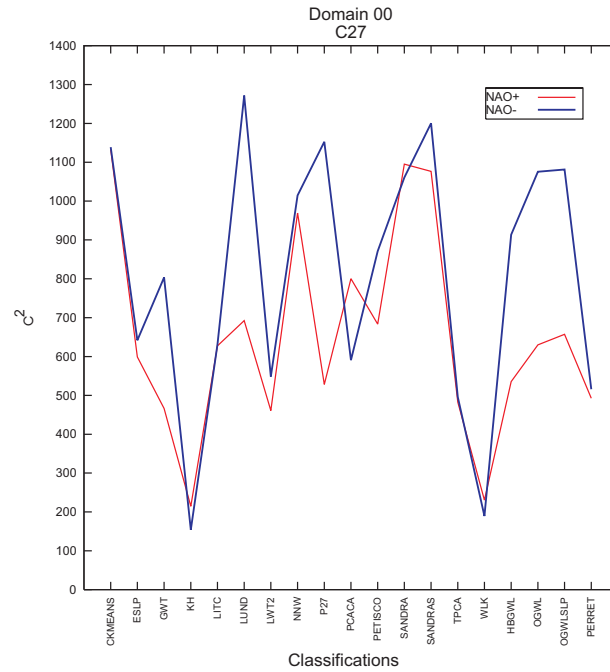


Figure 5.10: As in Fig.5.8, but for classifications of C27 sub catalogue (COST733CAT version 1.2).

was found in version 1.2. For NAO+, the best performance corresponds to OPT methods, for instance, CAP, CKM and SAN, especially in the case of CKM. Deterioration is observed when going from 1-day sequencing classifications to 4-day sequencing classifications, for PXX classification. The worst classifications are WLK from (THRES) and ERP from LEAD-based methods. With respect to version 1.2, KIR has slightly improved; this could be attributed to the different thresholds used in both versions of the catalogues. For NAO-, the best performance encompasses OPT and PCA families of algorithms, but depending on the specific sub-catalogue, the best classifications are for C09 PXX and KRZ classifications whereas for C27 sub-catalogue, KRZ and CKM (4-days sequencing and all variables) respectively. In C18, the best performance corresponds to LND classification (LEAD-based methods) when including SPZ5 (Sea Level Pressure and 500 hPa GPH) variables, followed by OPT-based methods, CAP classification (S04) with SP and SPY5 (sea level pressure and vorticity of 500 hPa GPH) and PCA-based methods, KRZ classification in both 1-day and 4-day sequencing, when using SP as input variable; and PCT, 4-day sequencing when dealing with all the combination of input variables. By way of contrast, KRZ improves when 4-day sequencing is taken into account, especially when dealing with 27 types. The worst performance are found in ERP_S01_SPY5 (LEAD-algorithm) and WLK S01_U7-V7-Z9. It is notorious, for PCA-based methods, that when considering all variables, there is a loss of discrimination.

(Continued on page 199)

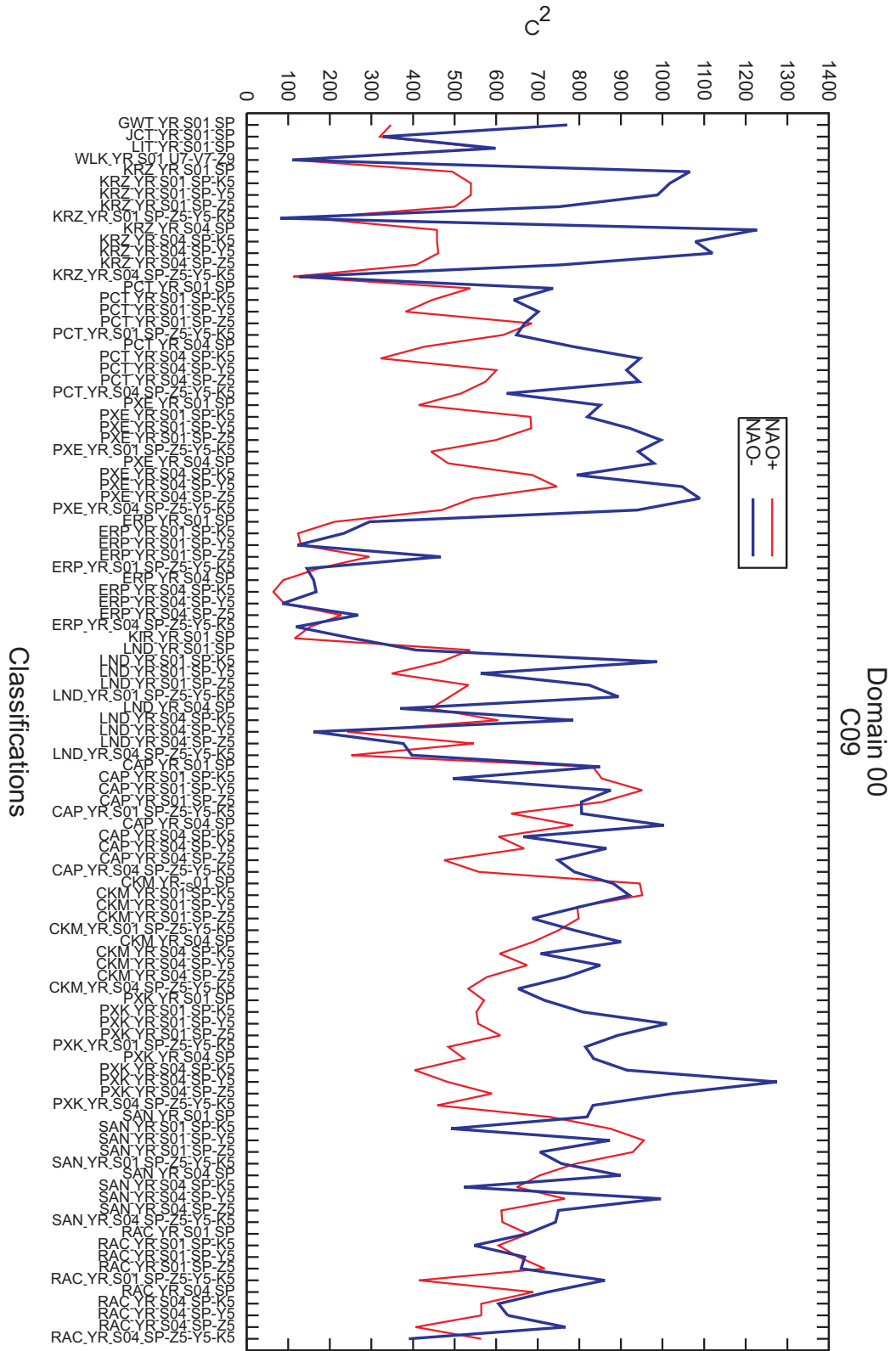


Figure 5.11: χ^2 values for NAO+ and NAO- for the classifications of C09 subcatalogue (COST733CAT version 2.0).

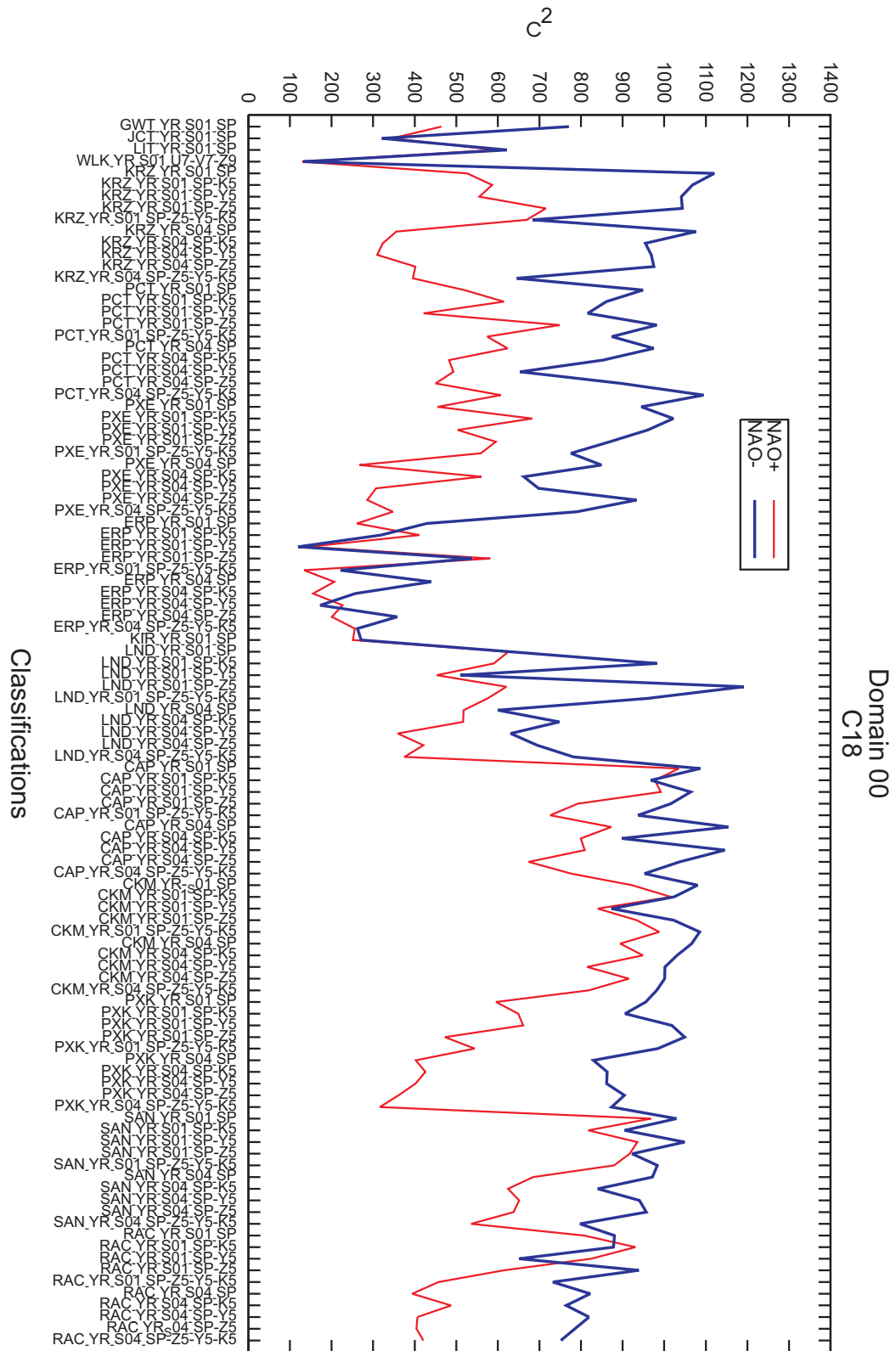


Figure 5.12: As in Fig. 5.11, but for classifications of C18 subcatalogue (COST733CAT version 2.0).

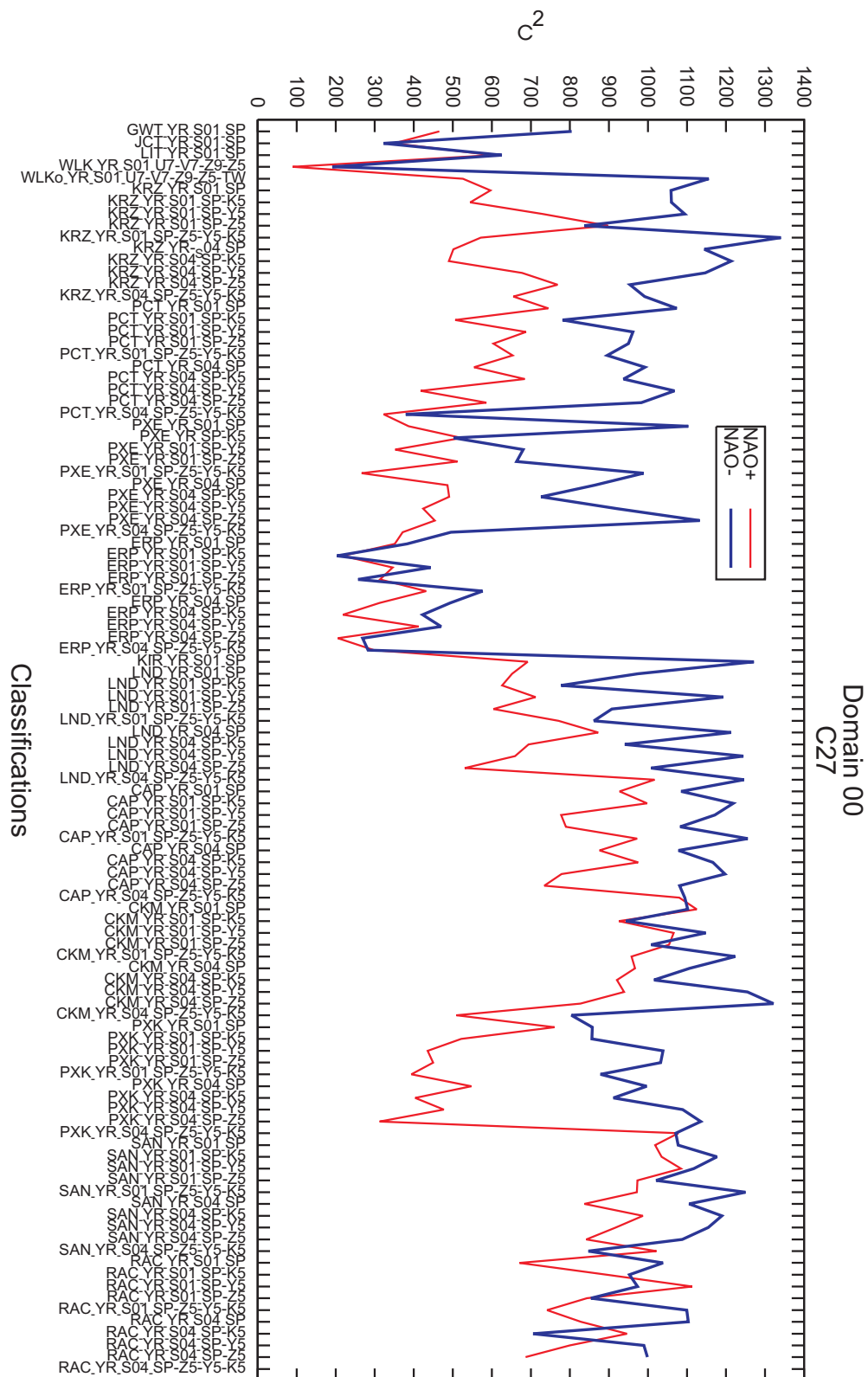


Figure 5.13: As in Fig. 5.11, but for classifications of C27 subcatalogue (COST733CAT version 2.0).

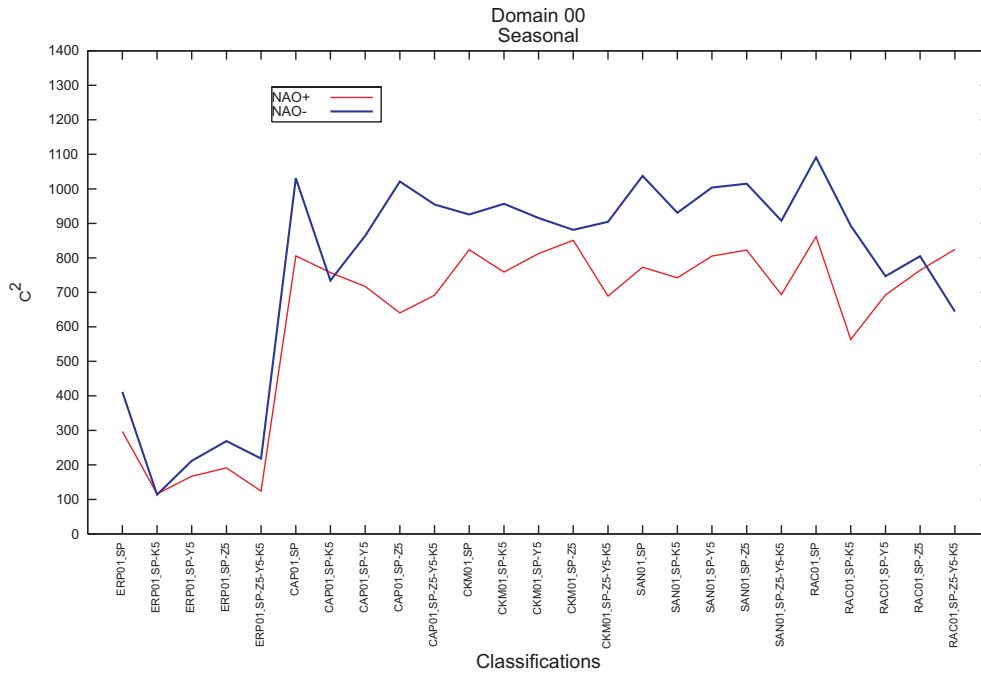


Figure 5.14: χ^2 values for NAO+ and NAO- in Domain D00 for classifications which are using seasonality (COST733CAT version 2.0).

Finally, for classifications defined seasonally (Fig. 5.14), for NAO+, the best performance is found in the Optimum Random Classification (RAC) with SP variable, followed by OPT methods, CKM classification with the combination SP-Z5; in the later cases, there is a deterioration when considering all variables. The worst performing corresponds to ERP classification (LEAD-based methods). For NAO-, practically, the pattern found for NAO+ is repeated; RAC classification performs best for SP; in the OPT algorithm family, the best classifications are CAP and SAN with SP as input data.

5.1.2.4 Summary and Conclusions

In this study, a ranking (based on χ^2) between many atmospheric circulation classifications is established according to their discrimination power of positive and negative North Atlantic Oscillation (NAO) phases. Generally, the classifications discriminate the negative NAO phase better than the positive NAO phase, for both versions of COST733 catalogues considered. This could be attributed to the fact that a negative phase takes place during episodes in which the normal circulation is interrupted. Consequently, a positive NAO phase can be characterised by patterns which are more variable and therefore belonging to a broader range of classified CTs.

a) For both versions 1.2 and 2.0 of cost733 catalogue

NAO+ phase is best discriminated by optimisation methods, regardless of the number of circulation types. By contrast, the classifications that best discriminate negative NAO phase encompass two families of algorithms (optimization and principal component analysis), with better results for higher number of classes. Finally, the worst discriminating classifications for all the sub-catalogues are WLK and KH (catalogue

version 1.2), belonging to the THRES and LEAD families of methods and in general, WLK and ERP (catalogue version 2.0).

b) In the cost733cat version 2.0

As a general rule, when sequencing, regardless of the classification algorithm used, the combination of SP and K5 (sea level pressure and thickness of 500 and 850 GPH level) fields performs reasonably well for NAO+, whereas the combination of SP and Z5 (sea level pressure and 500 hPa GPH) provides better results for NAO- respectively.

It can be observed that the consideration of additional variables and levels yields only little discrimination compared when using a single level, perhaps due to the high degree of dependence among individual levels (ROMERO et al., 1999). Importance of the global domain (D00) must be emphasized.

5.1.2.5 Recommendations

- **Family of algorithms**

Classifications that show a better performance correspond to the same family of algorithms, i.e. derived types with non-hierarchical cluster analysis. The classifications with the worst performance correspond to THRES (WLK) and LEAD (KH) family of methods. These results have been confirmed with the version 2.0 of COST733 catalogue.

- **Domain size and locations**

The use of a big domain is preferred. For the D09 (Iberia and western Mediterranean) domain, the χ^2 values are smaller than those of the D00 domain. The best classifications for both NAO phases correspond to the OPT family of algorithms while the worst classification correspond to the LEAD family of algorithms.

- **Number of classes**

An analysis of the impact of the number of CTs on the discrimination ability of the classifications has also been carried out. The χ^2 statistics shows as a general rule an improvement when the number of CTs increases.

- **Input variables**

As a general rule, for both NAO phases, no consistent dependency on input variable has been found; indeed, classifications belonging to the same family of algorithms do not share some common behaviour.

- **Seasonal**

For both phases, the best classifications belong to OPT methods whereas the worst correspond to ERP (LEAD-based methods).

- **Sequencing**

In general, with the exception of PCA-based classifications, it does not improve the results. As a general rule, regardless of the classification algorithm used, the combination of SP and K5 (sea level pressure and thickness between 500 hPa and 850 hPa geopotential height) fields performs reasonably well for NAO+, whereas the combination of SP and Z5 (sea level pressure and 500 hPa GPH) provides better results for NAO- respectively.

5.1.3 Circulation types and precipitation over Spain

Authors: Maria Jesus Casado and Maria Asuncion Pastor

5.1.3.1 Introduction

Precipitation over Spain displays a large variability on both intra -and inter-annual scales with, in some occasions, disastrous consequences due to its sporadic character and the irregularity of the events. A better understanding of the variability of precipitation hence is important; not only for improving long-range forecasting skill, but also for assessing regional impacts of climate change (CORTE-REAL et al., 1998). The variability of the large-scale atmospheric flow is an important factor in driving the variability of winter precipitation over the Mediterranean basin (CORTE-REAL and WANG, 1995; DÜNKELOH and JACOBET, 2003). Consequently, the great majority of the recent studies have focused mainly on the relationship between large-scale atmospheric modes of variability and precipitation over Spain and Portugal (ZORITA et al., 1992; RODÓ et al., 1997; RODRÍGUEZ-PUEBLA et al., 1998; GOODESS and JONES, 2002; MUNOZ-DÍAZ and RODRIGO, 2003). Nevertheless, only a few studies have focused on the relationship between different objective circulation classifications and precipitation over Spain (ROMERO et al., 1999; MARTÍN-VIDE, 2002; ESTEBAN et al., 2005), and even fewer have focused on the impact of the number of Circulation Types (CTs) considered in each classification on the description of the variability of precipitation (SANTOS et al., 2005). Most papers addressing the link between precipitation and atmospheric circulation using daily data are limited to specific Spanish regions (RODRIGO and TRIGO, 2007; LORENZO et al., 2007). Instead, in this study, both peninsular Spain and the Balearic archipelago have been considered (CASADO et al., 2010). These areas have been divided into climatic regions on the basis of their different precipitation climatology using a Principal Component Analysis (PCA), resulting in three Spanish climatic regions: Atlantic, Mediterranean and Northern (Fig. 5.15).

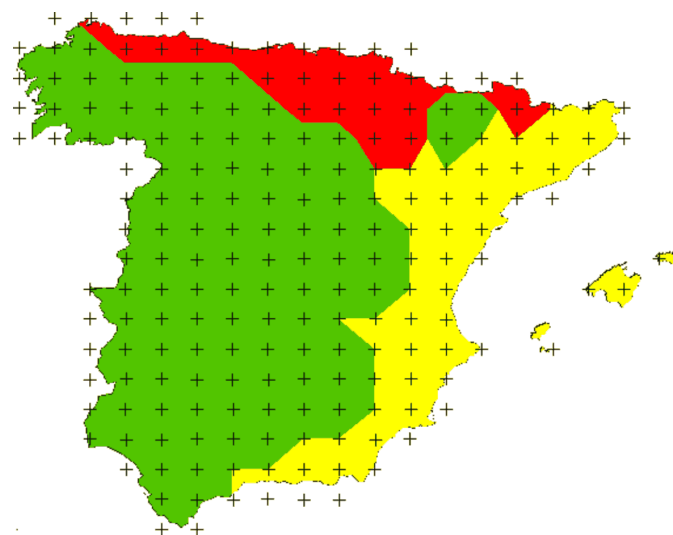


Figure 5.15: Grid-mesh of the precipitation data and study region of Spanish Atlantic (green), Spanish Mediterranean (yellow) and Northern Spain (red).

This study aims to improve the knowledge of the link between CTs and precipitation at a more coherent spatial scale, complementing the extensive recent research on the subject. This study assesses the discrimination capability of the winter variability of precipitation over Spain when using a large set of circulation classifications. The results might help to elucidate the relative merits of the most complete set of CT classifications based on the COST733CLASS software developed by [PHILIPP et al. \(2010\)](#).

5.1.3.2 Data and Methods

This research is based on a) a set of 53 classifications from COST733 catalogue version 1.2 those included in C09, C18 and C27 sub-catalogues and b) a subset of classifications of COST733CAT catalogue version 2.0 restricted to C18 sub-catalogue. The domain selected is D09, centered over the Iberian Peninsula. Meteorological information is from the ECMWF-ERA40 dataset at 12h ([UPPALA et al., 2005](#)). Daily gridded precipitation data on a high-resolution grid over Spain was obtained by [RIBALAYGUA et al. \(1997\)](#) for the period 1961–1990, derived from the climatological database of AEMET (State Meteorological Agency) using the inverse-distance method (minimum distance of 10-km) to interpolate the daily station data to 203 grid-points. The information at each grid point is representative of the average of their influence area. The meridional and zonal resolution is about 50 km and 60 km respectively. Analysis focuses on extended winter (December, January, February and March) as during that season, the atmosphere is dynamically more active and perturbations grow to their largest amplitudes, therefore exhibiting the largest variability over the extra-tropical regions (e.g. [KUSHNIR and WALLACE, 1989](#); [BLACKMON et al., 1984](#)).

The ability of the circulation classifications to reproduce the precipitation variability over different climatic regions of Spain was evaluated for the separability between types (discriminatory power) and the homogeneity within types (within variability) using a) the explained variation index (EV), b) the Pseudo-F index (PF) and c) the standard deviation (STD), this last one only for COST733 catalogue version 1.2. Due to the large spatial variation of precipitation over Spain, daily precipitation for each grid point was expressed as the contribution of that day to the winter total of that point, in percent.

5.1.3.3 Results

Circulation classifications were ranked according to their discrimination power using the above three metrics for each region. Particular attention was given to the impact of the number of CTs considered (version 1.2).

a) In the Spanish Atlantic region, for the COST733 catalogue version 1.2, EV suggests that the best classifications for all the sub-catalogues (C09, C18 and C27) are CKMEANS, PCACA and SANDRA (optimization methods (henceforth OPT), while the worst are NNW and subjective classifications, especially, HBGWT [Fig. 5.16(a)]. The EV confidence intervals [lower and upper extremes of coloured bars in Fig. 5.16(a)] are larger than for the other regions. The ranking obtained with PF is similar to that of EV results for all the subcatalogues (not shown). For the subset of COST733 catalogue version 2.0 (C18), for 1-day classifications, the best classifications belong to OPT methods, SAN classification with sea level pressure (SP) data and SPY5 (SP and vorticity of 500hPa) and the best optimum Random Classification (RAC) with SP data; whereas the worst are WLK with U7-V7-Z9 (zonal wind component at the 700 hPa GPH and

meridional wind component at the 700 hPa GPH level and 925 hPa GPH field) and KIR with SP data. With respect to 4-day sequencing classifications, the values are lower than when dealing with 1-day classifications, the best classifications belong to OPT methods, SAN with SP and SPY5 fields, whereas the worst is KRZ with SP field. [Fig. 5.17(a)].

b) In the Spanish Mediterranean region, EV values [Fig. 5.16(b)] are lower than those of the Spanish Atlantic region for all the sub-catalogues. This could be because precipitation over the Spanish Mediterranean region is mostly accumulated on a single season, autumn, when relatively small lows at 500 hPa are found about the southern part of Spain, and the associated low-level flow over the Mediterranean is warm and humid from the southeast (ITURRIOZ et al., 2007; ROMERO et al., 1999). For the three sub-catalogues, the best classifications are mainly relatives to the THRES methods (GWT, LWT2, and WLK, the only method utilizing multiple variables for classifications) and SANDRA related to OPT methods. Like for the Spanish Atlantic region, PF gives higher values in C09 sub-catalogue, PF confidence intervals generally overlap with those for the other sub-catalogues. For the subset of COST733 catalogue version 2.0 (C18), for 1-day classifications, the best classification belong to THRES methods, WLK with U7-V7-Z9-Z5-TW fields(zonal wind component at the 700hPa GPH, meridional wind component at the 700hPa GPH level, 925 hPa GPH field and TW), PXX (OPT methods) with SP as input data and LND (LEAD methods) with SPY5 as input data whereas the worst classifications are from PCA-based method, KRZ and KIR with SP data. With respect to 4-day sequencing classifications, the values are lower than when dealing with 1-day classifications, the best classifications belong to LEAD methods, LND classification with SPY5 as input data, and OPT methods, SAN with SPY5 data, whereas the worst are KRZ and LND with SP input data. [Fig. 5.17(b)].

c) In the Northern Spain, EV values [Fig. 5.16(c)] tend to be slightly larger than those for the Spanish Atlantic region for the C27 sub-catalogue. The similarities between Atlantic and Northern regions are not surprising because winter precipitation is generally stratiform induced mainly by Atlantic or Cantabrian depressions and associated frontal systems (ITURRIOZ et al., 2007). The best classifications, for the three sub-catalogues are CKMEANS, LITC, LWT2, P27, PCACA, and SANDRA. CKMEANS and SANDRA show very similar results. For the subset of CCOST733 catalogue version 2.0 (C18), for 1-day classifications, the best classification belong to OPT methods, SAN with SP and SPY5 as input data, followed by KRZ (PCA-based methods) with SP input data; whereas the worst classifications are from the WLK (THRES methods) with the combination of U7,V7 and Z9 input data. With respect to 4-day sequencing classifications, the values are much lower than with 1-day classifications; the best classifications belong to OPT methods, PXX and SAN with SPY5 input data, followed by PXE (PCA-based methods) with SPY5 and SPZ5 input data, whereas the worst is KRZ (PCA-based methods) with SP data. [Fig. 5.17(c)]

Using STD, the Spanish Mediterranean and Northern regions display a very similar behaviour to the Atlantic region. The increase of the number of CTs generally diminishes the discriminatory power of the classifications for all regions, and hence, the best performance corresponds to the C09 sub-catalogue. The best classifications (those with the higher STD values) refer to the OPT and PCA methods. The worst classifications correspond to the C27 sub-catalogue and are NNW and the subjective HBGWL, OGWLSLP, OGWL and PERRET.

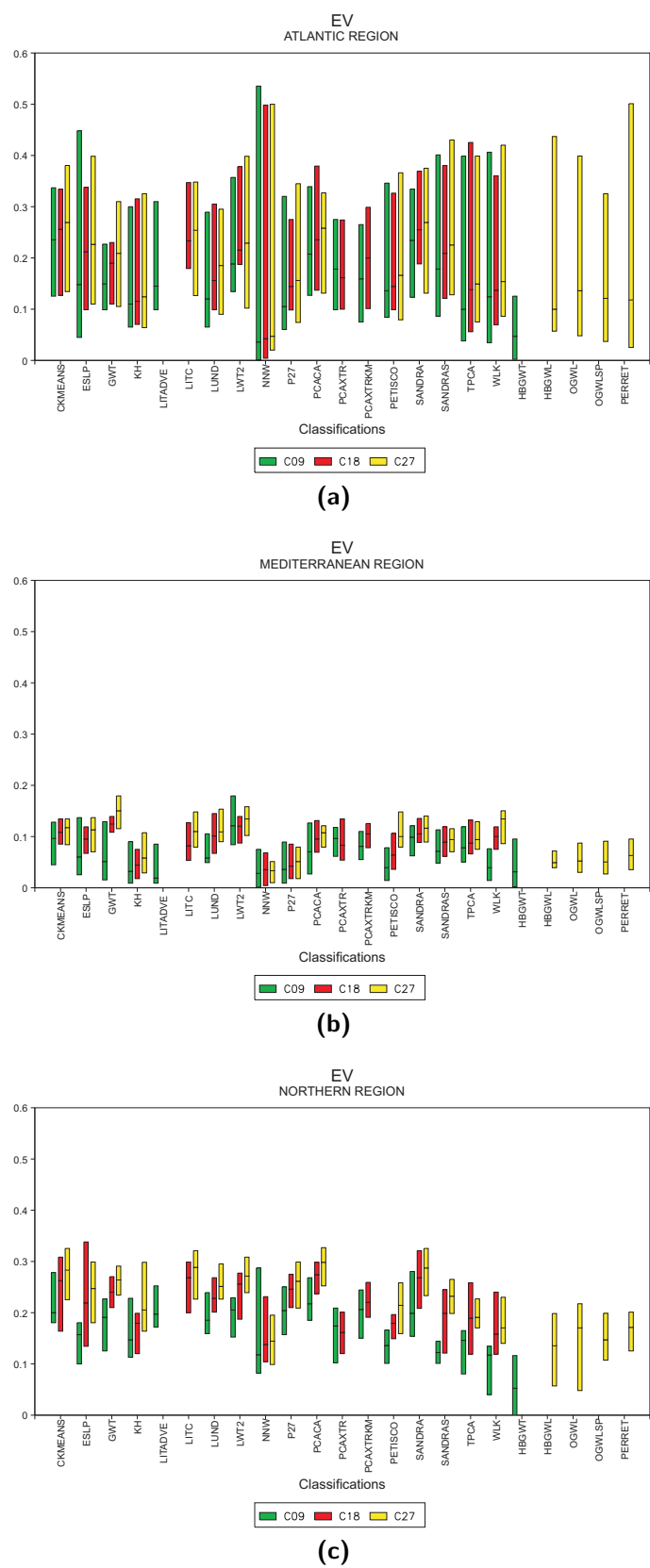
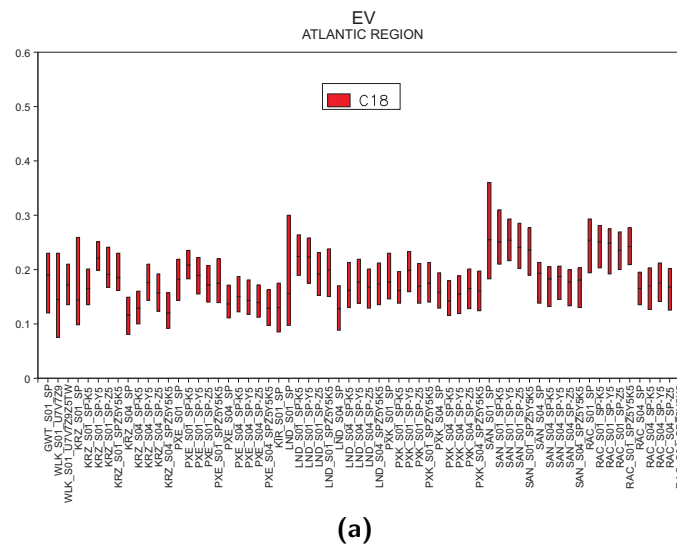
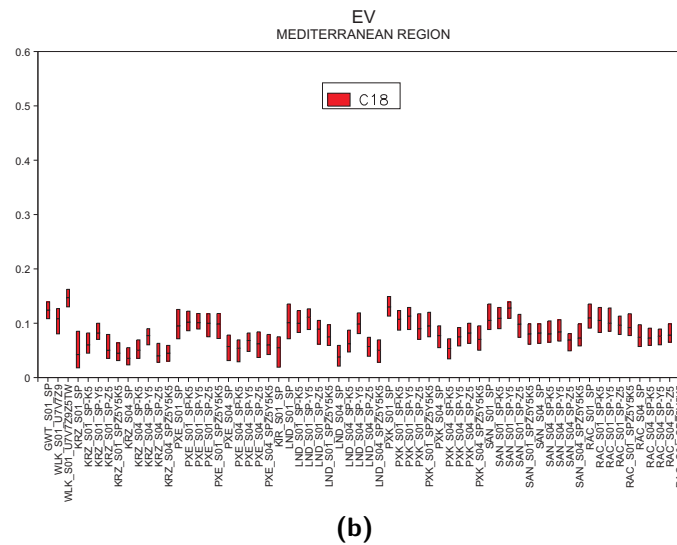


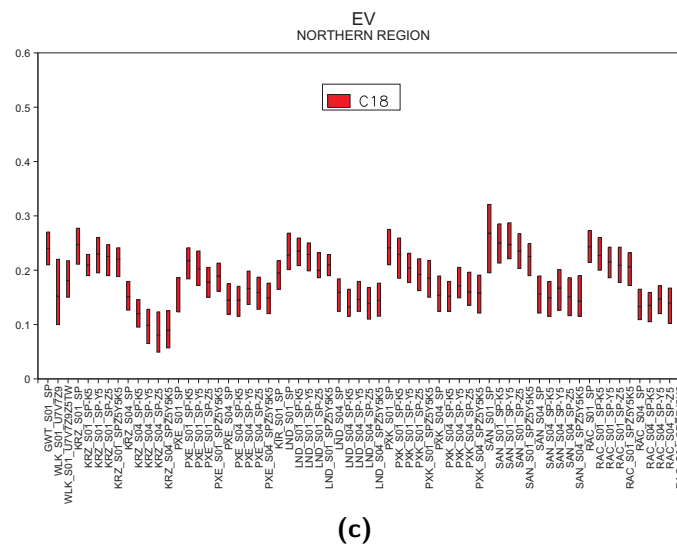
Figure 5.16: EV for (a) Spanish Atlantic, (b) Spanish Mediterranean and (c) Northern Spain for the C09 (green), C18 (red) and C27 (yellow). The EV values are shown with the black dash, inside the bars. Bottom and top of the bars correspond to the lower and upper extremes of the 95% bootstrap confidence intervals.



(a)



(b)



(c)

Figure 5.17: EV for (a) Spanish Atlantic, (b) Spanish Mediterranean and (c) Northern Spain for the C18 set of classifications (COST733CAT version 2.0).

5.1.3.4 Summary and Conclusions

A set of 53 objective classifications from COST733CAT v1.2 and a subset of objective classifications from COST733CAT v2.0 (C18 sub-catalogue) is used to identify a) the most suitable classifications that discriminate the winter precipitation variability over three climatic Spanish regions (Atlantic, Mediterranean and Northern), b) their sensitivity to the number of CTs considered, and c) the similarities/dissimilarities among the classifications belonging to the same group of methods whenever possible. Three metrics quantifying the within and inter-separability of the CTs of each classification were used: EV, PF and STD (only in catalogue version 1.2). The precipitation variability shows a great spread between the catalogues. The performance of the metrics depends on the region as well as on the number of CTs considered. According to EV and PF, the most discriminating classifications in the Atlantic and Northern regions are CKMEANS, PCACA and SANDRA (OPT or non-hierarchical cluster family of methods for all the sub-catalogues, and SANDRA for the catalogue version 2.0. In the Mediterranean region, the metrics have lower values than in the other regions, mainly because winter is not the rainiest season. This implies that the classifications are less able to discriminate winter precipitation variability in this region.

For both COST733 catalogues, it is noticeable that KRZ (P27) classification, included in the PCA group of methods, shows significant different results depending on the region. STD suggests PCAXTR, PCAXTRKM and PETISCO as the best classifications for C09 subcatalogue; PCAXTR, and PETISCO for the C18 and PETISCO for the C27 for the three regions (COST733 catalogues version 1.2).

In conclusion, for both catalogues, it has not been possible to find one single classification or one family of algorithms with the best overall performance on the basis of the metrics considered here. In particular, no single classification is the best to discriminate the precipitation over the Spanish climatic regions.

5.1.3.5 Recommendations

- **Family of algorithms**

For both versions of the COST733 catalogue, in the Atlantic and Northern regions of Spain, classifications that show a better performance correspond to the same type of algorithms, i.e. derived types with non-hierarchical cluster analysis. Instead, in the Spanish Mediterranean region, classifications using pre-defined types based on thresholds perform better. The classifications with the worst performance in every region belong to the NNW (Neural Network) and the subjective ones (version 1.2) and for version 2.0, KIR although there has been observed an improvement with respect to version 1.2, due to the introduced changes.

- **Domain size and locations**

The use of a smaller domain (D09) for the classifications is preferred.

- **Number of classes**

An analysis of the impact of the number of CTs on the discrimination ability of the classifications has also been carried out in COST733 catalogue version 1.2. Depending on the metric used, a different sensitivity of the classifications to the number of CTs has been found. The EV index shows an improvement when the number of CTs increases, whereas the PF and the STD metrics showed a negative impact with an increasing number of CTs.

- **Input variables**

In general, the best behaviour is detected with SP as input data, followed by SPY5 combination, especially in OPT classifications. This confirms the role of vorticity in precipitation considerations. Concerning WLK, best result is obtained with all the combination of variables.

- **Seasonal**

No conclusive evidence.

- **Sequencing**

As a general rule, regardless of the classification algorithm used, less discrimination is observed when dealing with 4-day sequencing data.

5.1.4 Links between circulation changes and climatic trends in European regions

Author: Monika Cahynová

5.1.4.1 Introduction

In recent decades the awareness of anthropogenic climate change has boosted research in the field of synoptic climatology. More and more studies are trying to attribute the climatic trends and variability to atmospheric circulation, taking into account either various characteristics of the pressure field (e.g. circulation indices) or synoptic types classifications.

Generally, the links are found to be more pronounced in the winter season (e.g. CHEN, 2000; HUTH, 2001; BECK et al., 2007; KOSTOPOULOU and JONES, 2007). The well-documented strengthening of zonal flow over Europe connected with a positive trend in the North Atlantic Oscillation in the decades preceding the 1990s is considered to be the main cause for the observed wintertime warming (HURRELL, 1995). When analyzing century-long or longer time series, several authors point out that the relationships between circulation and climate are changing on decadal time scales, thus strongly limiting the usefulness of statistical downscaling models (e.g. HANSSEN-BAUER and FØRLAND, 1998; BERANOVÁ and HUTH, 2008). Other causes than circulation changes (such as variations in the dynamic and/or climatic properties of the individual circulation types) are blamed for at least part of the local climate variability and trends (e.g. BECK et al., 2007; GOODESS and JONES, 2002).

In this study we quantify the links between large-scale circulation changes over Europe and local surface climatic trends in the period 1961–2000. The main aim is to compare the results of 24 circulation classifications from the COST733 catalogue version 1.2. To our knowledge, such a comparative approach has not been used so far. We further compare the classifications according to their skill to stratify daily climatic data into types. In both the analyses we focus on the effect of the number of types and the size of the spatial domain on the results. The analysis for the Czech Republic can be found in CAHYNOVÁ and HUTH (2010a).

5.1.4.2 Data and Methods

For the description of atmospheric circulation we have used 8 classification methods from the COST733CAT version 1.2 (CKMEANS, GWT, LITADVE-LITC18-LITTC, LUND, P27, PETISCO, SANDRA, TPCA), each applied on sea level pressure fields with a pre-defined number of circulation types (9, 18, and 27). The classifications were computed across the whole Europe and 11 European regions. The subjective Hess-Brezowsky catalogue (HBGWL, HBGWT) was used for comparison in the Czech Republic.

Meteorological data from the Czech Republic are represented by daily values of eleven variables at 21 stations in the period 1961–1998. The variables include daily maximum, minimum, and mean temperature, precipitation amount, the occurrence of precipitation, relative humidity, cloudiness (in tenths), and sunshine duration. At the European scale, we have used daily data of maximum (Tmax) and minimum air temperature (Tmin) and precipitation amount from 29 stations of the European Climate Assessment & Dataset in the period 1961–2000 (KLEIN TANK et al., 2002; KLOK and KLEIN TANK, 2009).

For the assessment of “skill” of circulation classifications to stratify daily climatic data into circulation types, we have applied the explained variance index (EV index). Seasonal circulation and climatic trends were estimated using linear least-squares regression applied to the seasonal occurrence of days with a specific circulation type (CT), and to the seasonal average of the given climatic variable. The common t-test was performed to evaluate the statistical significance of both circulation and climatic trends, and only the stations with climatic trends significant at the 95% level were further studied.

For the detection of relationships between changes in atmospheric circulation and trends in surface climatic variables, two methods were used: first the method of “hypothetical” (circulation-induced) linear trends (see, e.g. HUTH, 2001), and second the decomposition of climatic change that occurred between the 1st and the 2nd half of the study period (e.g. BECK et al., 2007) and described hereafter].

(1) Ratio of circulation-induced (“hypothetical”) and observed linear climatic trends

The first method, used e.g. by HUTH (2001) and CAHYNOVÁ and HUTH (2010a), is based on the notion of “hypothetical” trends which assume that changes in the occurrence of circulation types are the only factor causing the observed climate trends. All days classified with the same type are expected to bear the same value of a climatic element in a specific month (averaged over the whole period, e.g. all Januaries). Conditional mean values of each climatic element under every circulation type are calculated separately for each of the twelve months, and a time series is obtained by replacing the observed daily data by these conditional means. The new time series is then used instead of the observed data to assess the long-term “hypothetical” (circulation-conditioned) seasonal trends. These “hypothetical” trends are then compared with real changes simply by dividing them by the observed linear trends. This ratio would stay around one if climate trends were driven by circulation changes only. On the other hand, if the observed trends are caused by climatic properties of the individual CTs, the ratio is close to zero.

(2) Decomposition of climatic changes into frequency-related and within-type related parts

The second method of attribution of climatic changes, originally proposed by BARRY and PERRY (1973) and used e.g. by BECK et al. (2007) and CAHYNOVÁ and HUTH (2010a), is a simple decomposition of climatic difference between the averages of two subsequent or overlapping time periods (in our case between the 1st and the 2nd of the study period) ($\Delta\bar{C}$) into two parts – one related to changed climatic properties of individual circulation types (“within-type change”), and the other caused by changed frequency of circulation types (“frequency-related change”):

$$\Delta\bar{C} = \sum_{i=1}^G \left[\frac{\Delta F_i (C_i + \Delta C_i)}{n} + \frac{F_i \cdot \Delta C_i}{n} \right] \quad (5.2)$$

where G is the number of circulation types, F_i is the frequency of circulation type i during the first period, $F_i + \Delta F_i$ is the frequency of circulation type i during the second period, n is the number of time units during the first period, C_i is the climatic mean of circulation type i during the first period, and $C_i + \Delta C_i$ is the climatic mean of circulation type i during the second period. The expression $[\Delta F_i (C_i + \Delta C_i)/n]$ describes

the change in climate between the two periods due to frequency changes of circulation type i , whereas $[F_i \cdot \Delta C_i / n]$ depicts the degree of climate change assigned to a modified climate linked with circulation type i .

5.1.4.3 Results

The EV index is the highest for Tmax, lower for Tmin, and the lowest for precipitation. The highest values are reached at the Icelandic, Norwegian, and Alpine stations in winter. Classifications defined on small domains produce higher EV index than those defined on D00.

Using the first method of attribution, circulation changes in the classifications defined over small domains are responsible for about one fourth of the spring trends of Tmax and precipitation, and less for Tmin. In summer the circulation changes have virtually no influence on the observed trends, the ratio of circulation-induced and observed trends being close to zero in most cases (and sometimes even negative values occur). In autumn very few climatic trends are significant, and the influence of circulation changes on these trends is again very small for all the three variables (usually between 0 and 30%). It means that the within-type trends – i.e. changes in the internal climatic properties of individual circulation types – are the main driver of observed climatic trends in spring, summer, and autumn. This pattern occurs systematically over all stations and circulation classifications.

Winter is the only season when circulation changes play a major role in the observed climatic trends; however, there are some stations in the Balkans and the Mediterranean where the within-type changes are still more important even in this season. Circulation changes have a major influence (around or more than 50%) on the massive recent warming over the British Isles and Central Europe. Precipitation trends in winter are best resolved by circulation changes at one of the easternmost stations – Kyiv – that underwent substantial desiccation in 1961–2000, and this is the only case that the ratio of circulation-induced and observed trend reaches 1 (although only by one classification). The individual classifications produce very different results (see Fig. 5.18); note that average of all the stations with significant observed trend is shown). The results are usually higher for circulation types defined on smaller domains compared to D00, but in Iceland and Scandinavia the observed trends are better resolved by the large-scale circulation changes. The results are correlated with the number of circulation types.

The second method of attribution of climatic changes (used by [BECK et al., 2007](#)) gives fairly similar results, only in winter in Central Europe the frequency-related part of climatic change between the 1st and the 2nd half of the period is higher and reaches 50 to 100%. In the Czech Republic the same analysis was performed at 21 stations in 1961–1998 (see [CAHYNOVÁ and HUTH, 2010a](#)). The results are consistent to those obtained for other Central European stations in the period 1961–2000. In winter the circulation influence on climate variables trends is the highest for temperature and lower for precipitation occurrence, relative humidity, and sunshine, while in spring and summer the results for temperature are lower than for the other variables (in autumn the values are about the same). The variability within results from individual stations is comparable to the variability produced by the 24 objective circulation classifications. There is no clear dependence of the results on the geographical position of the stations.

The subjective Hess-Brezowsky catalogue with 29 types (HBGWL) and 10 types (HBGWT) produce a substantially higher proportion of circulation-induced climatic

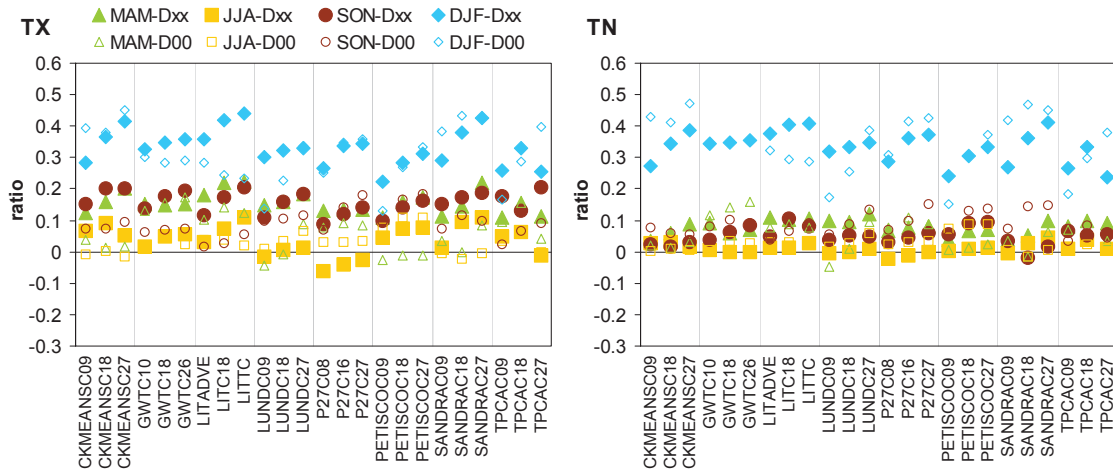


Figure 5.18: Ratio of circulation-induced and observed climatic trends (i.e. the proportion of observed trends directly linked to changing frequency of CTs) in 1961–2000. Average of European stations where seasonal observed trends are significant at the 95% level.

changes in the Czech Republic than the objective catalogues for both methods of assessment in winter for temperature, and in autumn and spring for nearly all climatic variables (not shown). The reason might be that in the HBGWL and HBGWT catalogues, more circulation types bear significant seasonal trends in their frequency compared to the objective catalogues.

5.1.4.4 Summary and Conclusions

We evaluate and compare 24 circulation classifications from the COST733CAT 1.2 according to their ability to stratify daily station climatic data into circulation types, and assess the magnitude of seasonal temperature and precipitation trends in Europe in the period 1961–2000 (and in the Czech Republic in 1961–1998) that can be linked to changing frequency of circulation types in these classifications. The skill to stratify climatic data into types (measured by explained variance index) is the highest for maximum temperature, lower for minimum temperature, and the lowest for precipitation. The highest values are generally obtained in winter for classifications with 27 types that are computed on the small spatial domains.

Seasonal climatic trends can only be partly explained by the changing frequency of circulation types, the link being the strongest in winter. In the other seasons, within-type climatic trends are responsible for a major part of the observed trends. Circulation changes in the small domains are usually more tightly connected with climatic trends than those in the large domain except for Icelandic and Scandinavian stations where circulation over the whole Europe explains a larger part of the observed trends. There are large differences between results obtained with individual classifications, which suggests that a comparative approach is highly desirable in such synoptic-climatological studies.

5.1.4.5 Recommendations

- **Family of algorithms**

No clear result: the ranking varies for different seasons and climatic variables.

- **Domain size and locations**

Small scale is usually more tightly linked to climatic variability and trends. Exception: winter and spring climatic trends in Iceland and Scandinavia are better described by circulation changes in the large domain.

- **Number of classes** More CTs usually means better separability of daily climatic variables into them (this results from the definition of EV index), and also larger proportion of climatic trends that can be attributed to circulation changes. Exceptions occur.

5.1.5 Relations between atmospheric circulation and precipitation in Belgium

Authors: Erwan Brisson, Matthias Demuzere, Bert Kwakernaak and Nicole P.M van Lipzig

5.1.5.1 Introduction

The goal of this case-study is to improve, using both descriptive and inference statistics, our understanding of precipitation variability in the mid-latitude coastal region of Belgium by investigating the relation between precipitation variability on different time scales and atmospheric circulation as defined by an objective classification of circulation types. In addition, the geostrophic wind speed, also derived using the sea level pressure (SLP) is studied on whether it could explain more of the precipitation variability in the present-day climate. As circulation-types are in general the basis for a great deal of the statistical downscaling methods, our study is a first step in the development of a precipitation statistical downscaling method for Belgium ([BRISSON et al., 2010](#)).

5.1.5.2 Data and methods

Daily precipitation observations derived from a tipping bucket system from the Belgian weather station network are obtained from the Royal Meteorological Institute (RMI) for the period 1962-1999 for six sites spread around Belgium. From the descriptive statistics (not shown) one can see that precipitation increases from about 2 mm per day close to the coast (in western side of Belgium) to 4 mm per day in the Ardennes (the low mountain range in the eastern side of Belgium). In Belgium, much of the precipitation is related to fronts, which are associated with cyclonic events, coming from the West. The occurrence of precipitation is on average 200 days per year. In the Ardennes precipitation occurrence increases to 216 days with a maximum of 230 days and a standard deviation of about 25 days (not shown). Daily circulation patterns at the regional scale are derived from sea level pressure data from the ECMWF (European Centre for Medium-range Weather Forecasts) ERA40 reanalysis dataset on a $2.5^\circ \times 2.5^\circ$ grid for the larger European Atlantic Region (27.5°W – 27.5°E , 85° – 15°N) centered above Belgium. Daily mean sea level pressure (MSLP) data is obtained for the period 1962–1999 by averaging the 6-hourly sea level pressure values available at 00 UTC, 06 UTC, 12 UTC and 18 UTC.

The objective Jenkinson-Collison circulation types describe for a given day the location of the high and low-pressure centers that determine the direction of the geostrophic flow. A grid with 16 points, separated by 5° from each other, is assigned over the larger western and central Europe, with a central point at 50°N and 5°E . This method allows $26 + 1$ (unclassified – U) different CTs to be defined, including eight main directional types: north (N), north-east (NE), east (E), south-east (SE), south (S), south-west (SW), west (W), northwest (NW) and two vorticity types: anticyclonic (A) and cyclonic (C). In addition, sixteen hybrid types (combination of directional and non-directional types) are defined ([LAMB, 1972](#)). In order to devise a practical, though reliable, statistical analysis scheme, the 27 circulation types are re-grouped into 11 basic ones so that each of the 16 hybrid types was included with a weight of 0.5 into the corresponding pure

directional and cyclonic/anticyclonic types. For example, one case of CSW is included as 0.5 in C and 0.5 in SW.

For each CT, the precipitation occurrence is derived from the daily amount of precipitation. A day is defined wet when the amount of precipitation is higher than 0.3 mm, because under this threshold the presence of dewdrop can distort the result (Tut et al., 2005). A correlation between a given CT occurrence and both precipitation occurrence and amount is expected if the atmospheric circulation is able to organise the main precipitation characteristics.

The ability of a model to reproduce precipitation variability, based on CT occurrence is studied on a monthly scale in the present-day climate. It consists of a simple linear regression model (LRM) in which wet-CT occurrence is a predictor. Both precipitation occurrence and amount are modelled.

Finally, two indices defined by GOODESS and JONES (2002), namely the normalised relative occurrence of rainy days per CT ($PROP_{ct}/PROP_{tot}$) and the normalised relative daily intensity of precipitation per CT ($PREC_{ct}/PREC_{tot}$) are used to analyse spatial and temporal precipitation variability:

$$\frac{PROP_{ct}}{PROP_{tot}} = \frac{N_{wet_{ct}}/N_{ct}}{N_{wet_{tot}}/N_{tot}} \quad (5.3)$$

where $N_{wet_{ct}}$ is the total number of wet days within the CT, N_{ct} is total number of days within the CT, $N_{wet_{tot}}$ is the total number of wet days within the entire 38-year period, N_{tot} is total number of days within the entire 38-year period. The normalized relative daily intensity of precipitation can be written as:

$$\frac{PREC_{ct}}{PREC_{tot}} = \frac{TAR_{ct}/N_{wet_{ct}}}{TAR_{tot}/N_{wet_{tot}}} \quad (5.4)$$

where TAR_{ct} is the total accumulated rain during the wet days of a specific CT, $N_{wet_{ct}}$ is total number of wet days within the CT, TAR_{tot} is the total accumulated rain during the wet days of the entire 38-year period, $N_{wet_{tot}}$ is total number of wet days within the entire 38-year period. An index higher than one means that there is a positive anomaly, viz. a high chance of precipitation occurrence ($PROP_{ct}/PROP_{tot}$) for a specific CT compared to the average over all the CTs. An index $PREC_{ct}/PREC_{tot}$ higher than one shows that the intensity of rainfall on a wet day is, for a given CT, larger than the average intensity on a wet day during the entire 38-year period. Inversely an index lower than one indicates a negative anomaly. More information on these indices can be found in GOODESS and JONES (2002).

5.1.5.3 Results

When studying the spatial variability, it was found that precipitation increases going from the coast (western side of Belgium) to the low mountain range of the Ardennes (eastern side of Belgium), especially for W and NW circulation types. This gradient is related to the orography: the Ardennes massif is orientated from the South-West towards the North-East and therefore the flow is perpendicular to the low mountain range of the Ardennes when it is coming from westerly to north-westerly directions. Consequently, for these CTs the orographic lifting of air is largest. Based on the normalised relative occurrence of rainy days per CT and the normalised relative daily amount of precipitation per CT the stations have been clustered into three groups: the coastal station Koksijde,

the stations representative for the flat interior (Eeklo, Uccle and Genk) and the stations located in the low mountain range of the Ardennes (Saint-Hubert and Gouvvy).

By analysing the distribution of average precipitation intensity within the CTs it is found that the highest probability of extreme precipitation is during cyclonic CTs in summer. The median daily precipitation amount is largest during summer and autumn for the N-CT and the C-CT, probably due to convective triggering of precipitation: During N-CT cold air is advected over the warmer land surface and during C-WT the air is destabilised due to upward vertical motion. A relation between geostrophic wind speed and internal precipitation variability for some CTs is found when considering ten-day means.

A linear regression model (LRM) is used to study how much of the variability in precipitation can be explained by CTs. It was found that the LRM can reproduce the monthly precipitation variability for the present day climate better during winter and autumn than in summer, when convection is dominant.

5.1.5.4 Conclusions

In summary, the analysis based on Jenkinson-Collison CTs allows a better physical understanding of the relation between precipitation and atmospheric circulation and is a first step toward the development of a precipitation statistical downscaling method for Belgium. A method based on atmospheric circulation variables only is promising for downscaling precipitation distribution on a monthly scale. The variability in monthly mean precipitation that can be explained by CTs in winter and autumn is 60% and 40% respectively.

5.1.5.5 Recommendations

- **Family of algorithms**

The use of a wind direction based classification methodology is shown to be useful to explain precipitation variability for a region mainly influenced by zonal precipitation advection. Other methods are not tested in this study.

5.1.6 The dependence between circulation types and weather types at the Polish synoptic stations

Author: Krystyna Pianko-Kluczynska

5.1.6.1 Introduction

Long-range forecasters search for the best method to determine weather anomalies in the forthcoming month. In other words, they are looking for an answer to the question: should the forecasted month be dry, standard or wet and cold, standard or warm i.e. will the deviation from long-term average be distinctly negative, near zero or distinctly positive? This case study searches for the relationship between the number of circulation types occurrence and described above monthly weather anomalies.

These anomalies depend on location of high and low pressure centres which determine direction of inflowing air masses. In this respect it is hoped that given classification types are directly linked to some monthly weather characteristics, as reflected by the correlation between the occurrence of a classification type and a monthly anomaly of weather variable. Significance is given when the empirical correlation is greater than 0.5.

5.1.6.2 Data and methods

This study is based on COST733CAT v.2.0 for domains D00, D05, D06 and D07 for all number of classes. The analysis is made on for departures from long-term monthly average of minimum (TMIN) maximum (TMAX) and daily (TAVE) temperature, monthly rainfall totals (TPREC) and number of days with precipitation (NUMDAY). On the basis of size and character of the departure, it can be specified the general nature of the monthly weather for temperature and precipitation (below normal, in the standard or above normal). The data is derived from eleven Polish synoptic stations: Koszalin, Gdansk, Suwalki, Chojnice, Poznan, Warszawa, Zielona Gora, Wroclaw, Lodz, Lublin and Krakow. Correlation $Cor(C_{NT}, X_i)$ is calculated between C_{NT} and weather anomaly X_i , where C_{NT} it is the number of days with the circulation type $NT(= 1, 2, \dots, LT)$ with $LT =$ the number of types of circulation. $Abs(Cormax)$ is the maximum correlation $Cor(C_{NT}, X_i)$. This analysis was conducted during the whole year and seasons.

$Abs(Cormax)$ determines the strength of relationships between meteorological variable and the classification of circulation, i.e. its usefulness in the production of monthly forecasts. On the basis of this indicator we suggest a classification method ranking. This analysis was conducted during the whole year and seasons. For each station all classifications from one domain (423 catalogues) have been sorted in descending order on the basis of $Abs(Cormax)$. If the position k of the classification is in the top five of the 423, its weight increases by $6 - k$ and otherwise it remains unchanged. Taking into account all stations, each classification is assigned weight in the range of 0–55. Circulation classifications with the highest weights are recommended for further use. To provide recommendations listed in points 1–6 all classifications were divided into appropriate subgroups. Sub-set with the highest average value of $Abs(Cormax)$ was recommended.

5.1.6.3 Results

As shown in Fig. 5.19, depending on the selection of season, synoptic station and domain, strength of the relationship between circulation type occurrence and meteorological variables can vary considerably. On the left diagram recommendations for TMAX in the whole year for Chojnice series and D06 domain are shown (weakest link) and the right one – TMAX for Zielona Gora in the winter season with domain D07 (strongest correlation).

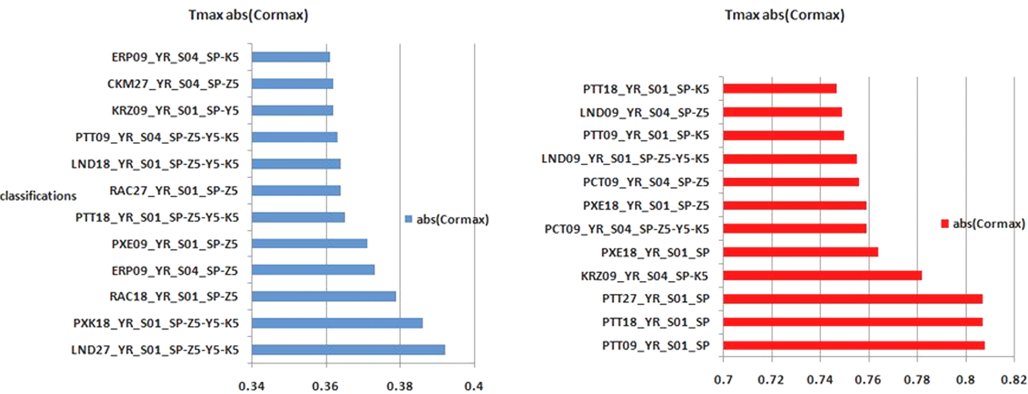


Figure 5.19: $Abs(Cormax)$ for the best 12 classifications for TMAX (blue–Chojnice_YEAR, red–Zielona Gora_DJF).

The results of experiments confirm the hypothesis that different atmospheric factors determine weather anomalies in particular seasons. Therefore, it is difficult to find a circulation type classification with strong links with climate anomaly during the entire year. This is illustrated with the strongest correlations not exceeding the boundary value of 0.5.

Fig. 5.20 illustrates the recommendations of the “top five” in Tab. 5.2 and Tab. 5.2. Y-axis indicated a number of occurrences of representatives of the subgroup among 27 classifications listed in these tables.

Fig. 5.21 shows an attempt to three-dimensional visualization of the resulting rankings. The vertical axis indicated the absolute values of correlation.

Table 5.2: Best circulation classifications to discriminate temperature anomaly in Poland (annual and seasonal series), based on correlation analysis.

<i>Variable</i>	<i>Season</i>	<i>Weight</i>	<i>Classification</i>
Tmax	Year	54	ERPo10_YR_S01_Z5_D05
Tmax	DJF	52	PTT27_YR_S04_SP-Y5_D00
Tmax	MAM	55	PCT09_YR_S01_SP-Z5_D05
Tmax	JJA	52	WLKo40_YR_S01_U7-V7-Z9-Z5-TW_D00
Tmax	SON	54	PXK16_YR_S01_SP_D07
Tmin	Year	55	RAC27_YR_S04_SP-Z5_D07
Tmin	DJF	54	PCT27_YR_S04_SP-Z5_D05
Tmin	MAM	48	PCT09_YR_S01_SP-Z5_D05
Tmin	JJA	43	WLKo40_YR_S01_U7-V7-Z9-Z5-TW_D00
Tmin	SON	53	PXE18_YR_S01_SP-Z5_D05
Tave	Year	55	RAC27_YR_S04_SP-Z5_D07
Tave	DJF	53	PCT27_YR_S04_SP-Z5_D05
			PTT09_YR_S01_SP_D07
Tave	MAM	55	PCT09_YR_S01_SP-Z5_D05
			PCT09_YR_S04_SP-Z5-Y5-K5_D07
Tave	JJA	50	PXE17_YR_S04_SP-Z5_D06
Tave	SON	52	PCT18_YR_S01_SP-K5_D05

Table 5.3: Best circulation classifications to discriminate precipitation in Poland (annual and seasonal series), based on correlation analysis.

<i>Variable</i>	<i>Season</i>	<i>Weight</i>	<i>Classification</i>
Tprec	Year	51	WLKo27_YR_S01_U7-V7-Z9-Z5_D00
Tprec	DJF	29	PTT09_YR_S01_SP_D06
Tprec	MAM	34	WLKo15_YR_S01_U7-V7-Z9_D00
Tprec	JJA	41	WLKo27_YR_S01_U7-V7-Z9-Z5_D00
Tprec	SON	33	PXK17_YR_S01_SP-Y5_D00
Numday	Year	52	LND09_YR_S04_SP-Y5_D07
Numday	DJF	39	PXK18_YR_S01_SP-Y5_D05
Numday	MAM	40	LND18_YR_S01_SP-Y5_D00
Numday	JJA	54	WLKo27_YR_S01_U7-V7-Z9-Z5_D00
Numday	SON	39	ERP28_SE_S01_SP-K5_D06

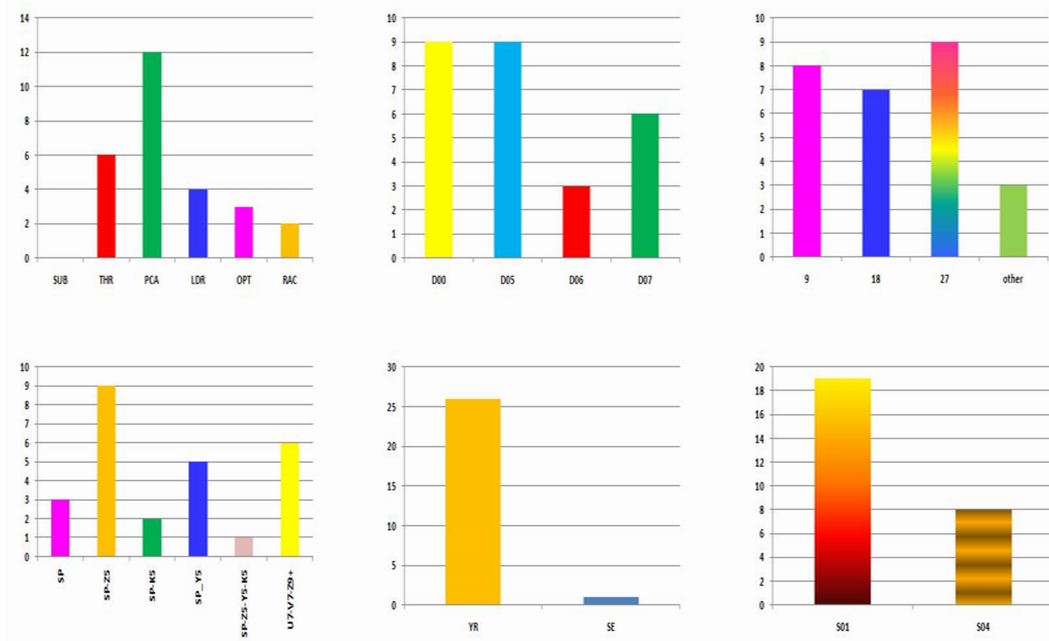


Figure 5.20: Summary of recommendations for number of classifications in subgroups (family of algorithm, domain size and location, number of classes, input variables, seasonality and sequencing).

5.1.6.4 Summary and conclusions

Correlation index $Abs(Cormax)$, calculated for different seasons of the year are higher (often above 0.7) than those for the whole year (sometimes below 0.5). These results confirm the difficulty to find a single circulation classification with strong links to weather anomalies for all months. The need to use different classifications for different seasons is not contrary to the recommendation for the types defined for the year (YR) because in the subgroup SE classifications have less than 9 types for each season.

5.1.6.5 Recommendation

- **Family of algorithm**

The most appropriate classification groups to discriminate temperature anomaly seem to be PCA and LDR, while for precipitation PCA, LDR and THR. Results for PCT09 were excluded as a single type can persist for almost a whole month.

- **Domain size location**

Domain D00 (for the seasons DJF, MAM and SON), D05 (especially for MAM and SON), D07 (without MAM) are recommended for temperature. For precipitation domain D06 and D07 seem to be the most appropriate.

- **Number of classes**

It is difficult to recommend the optimal number of types. Ultimately, at least 27 types are recommended, however 9 types classifications should not be entirely excluded.

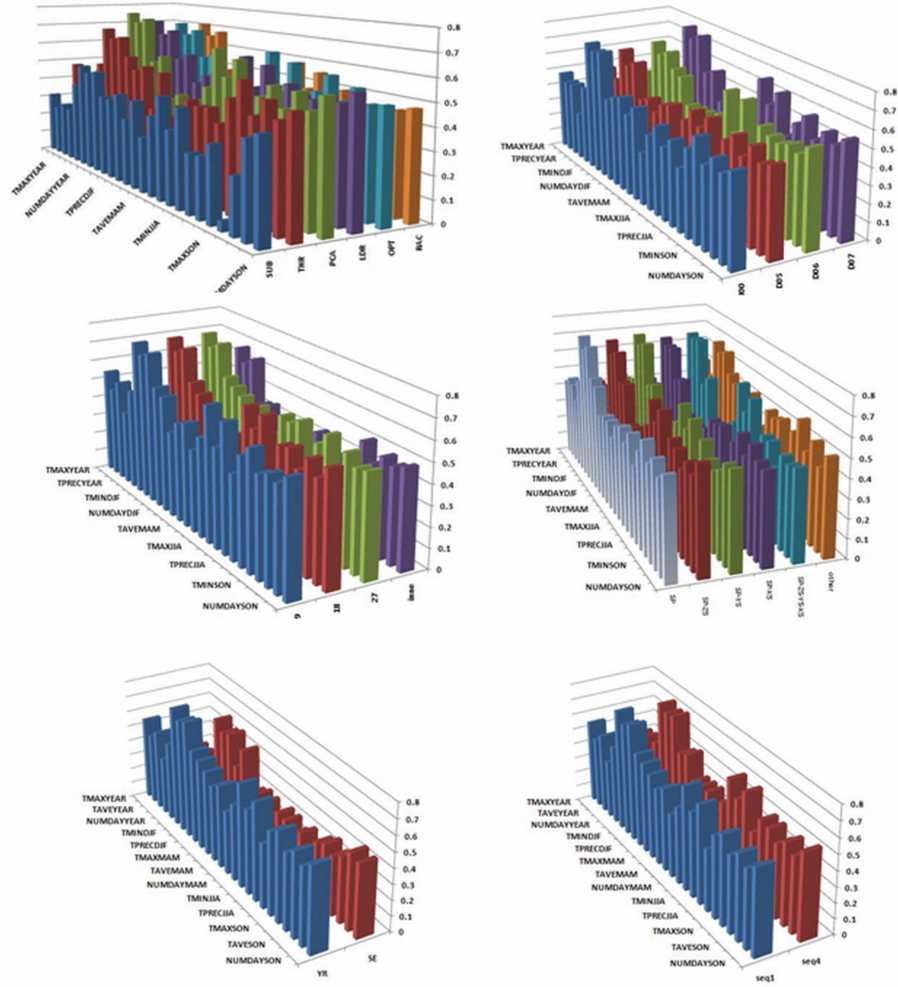


Figure 5.21: *Cormax* recommendations: max value of $\text{abs}(\text{Cormax})$ in subgroups (family of algorithm, domain size and location, number of classes, input variables, seasonality and sequencing).

- **Input variables**

SLP and SLP-Z5 are optimal input variables. Input U7-V7-Z9-Z5 is also recommended for the whole year and the spring.

- **Seasonality**

It is recommended to use types defined for the year (YR) and not for individual season (SE).

- **Sequencing**

It seems advantageous to use a four sequence (S04) for variable TMIN in DJF and JJA, and for variables TPREC and NUMDAY in JJA. In other cases it is recommended to use classifications based on one-day sequence (S01).

5.1.7 On Regime Shift in the General Atmospheric Circulation over the Baltic Sea Region

Author: Mait Sepp

5.1.7.1 Introduction

There are several different methods for analyzing the effects of climatic changes in the general atmospheric circulation. One way is to study the periodic changes in the atmospheric processes, as cyclic changes in the frequency of circulation types are of paramount importance in synoptic climatology. Leningrad-based G. Vangengeim and later A. A. Girs built their long-term forecast methods on ‘epochs’ during which certain circulation types would dominate for a decade ([GIRS, 1971](#)). In determining the ‘epochs’, the critical question is when one epoch or its stage ends and another begins. According to Vangengeim and Girs ([GIRS, 1971](#)), such changes take place quite rapidly – the frequency of one circulation type (or group of circulation types) increases, while the frequency of others (e.g. meridional circulation types) decreases. A rapid change or a shift in regime follows.

The aim of the current research is to study whether the possible regime shifts are also visible in the atmospheric circulation classifications of the catalogue 1.2 of COST733. When such shifts are visible, we analysed when and in which classifications and directions these changes have taken place, and for which circulation types.

5.1.7.2 Data and methodology

The 73 circulation classifications of COST733CAT v1.2 catalogue for Domain D05 were analysed annually and seasonally, with the seasons taken as winter (DJF), spring (MAM), summer (JJA) and autumn (SON). Regime shift was identified using the software (Excel macro) developed by S. N. Rodionov from the Washington University ([RODIONOV, 2004](#); [RODIONOV and OVERLAND, 2005](#)).

The method is based on the sequential application of the Student’s t-test where the user defines cut of length – the length of the period for the t-test used to identify a statistically significant shift in the series – shifts in mean or variance. The effect of extreme values can be harmonized using Huber’s Weight Parameter [[RODIONOV2005](#)]. Red noise can be detected from three methods and pre-whitening of time series performed. As suggested by [RODIONOV \(2004\)](#) and [RODIONOV and OVERLAND \(2005\)](#), the pre-analysis stage quantified the impact of choice in the method and cut length.

The conclusion was that it was best to use analysed shifts in the mean, using a significance level of 0.1, a cut-off length of 10 years and a Huber’s weight parameter of 1. The effect of red noise was not analyzed and the pre-whitening was not performed. Artificial shifts on the last 4 years of random series were systematically found on randomly-generated series, suggesting that the methodology was not reliable to detect shifts in the later part of the analysed period, but were good for the rest.

5.1.7.3 Results

Most regime shifts took place between the years 1998–2002 when individual circulation types were analyzed annually, but during the ‘unreliable’ part of the record (final years).

Ignoring any shift suggested within the last four years, 63 regime shifts in the circulation types were found to occur in 1989 (Fig. 5.22), divided between 19 negative and 44 positive. The second main shift occurred in 1971. The 63 shifts detected in 1989, however, only represent a very small proportion of the total number of circulation types analysed (about 1370), and correspond to one or two circulation types in about two third of the classifications (29 out of the 73 classifications had no shift in 1989).

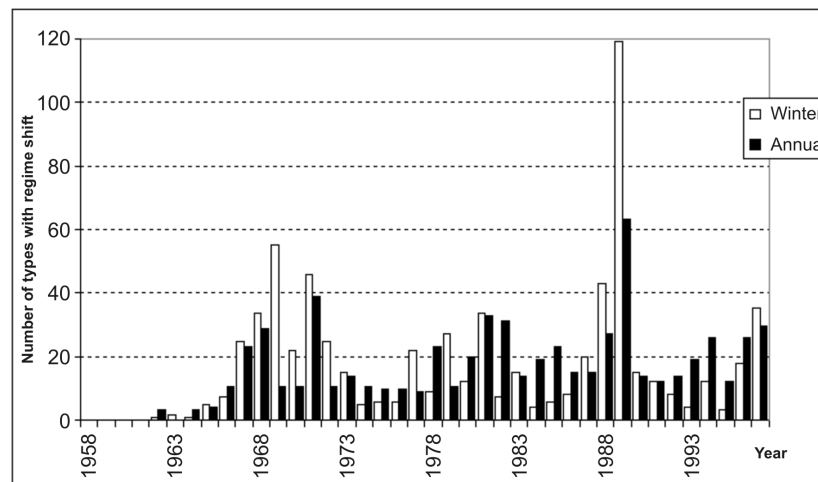


Figure 5.22: The number of circulation types in which significant regime shifts in frequency have occurred in the respective year in both the winter and annual sum. Years 1998–2002 are excluded.

Significant differences were found from the seasonal analysis, where shifts in 1989 were mainly detected in winter and spring but not in summer and autumn. Summer, autumn and also winter seasons show considerable shifts in the end of 1960s, which differed slightly with the 1971 shift found from the annual analysis, as shifts in summer occurred in 1968, and in autumn and winter in 1969. Because the Baltic Sea region sees the most rapid climatic changes in the winter season, we then analyzed the 119 circulation types that have undergone a significant shift in the winter of 1989 (59 with negative shift and 60 with a positive shift). In only 9 classifications (HBGWL, HBGWT, OGWL, PERRET, TPCA07, TPCAC09, TPCAV, WLKC28, WLKC733) no such shifts occurred.

The circulation types with positive (negative) shifts were compared using correlation. The results showed positive strong correlations (at the level of the statistical significance of $p < 0.05$), thus suggesting that all the circulations represent similar processes. The correlation matrix was then studied by cluster analysis (K-means). The circulation types with a negative shift could be divided into five classes, and the corresponding composite plots of MSLP showed relatively similar atmospheric pressure area division types (Tab. 5.4). The conclusion is that the regime shift of 1989 corresponded to a decrease in the frequency of three types of circulation:

- high pressure area in the northern or north-eastern part of the domain;
- high pressure area in the eastern part of the domain and/or a low pressure area in the western part of the domain;
- low pressure area in the central part of the domain.

Table 5.4: The circulation types with negative regime shift in the winter of 1989 divided in five classes. An asterisk marks those types whose atmospheric pressure division on the MSLP figure does not correspond to the description of their class.

High over the northeastern part of the domain	EZ850C10 t5*, GWTC10 t9, KHC09 t3, KHC18 t3, KHC27 t3, LITADVE t4, LWT2C18 t4, NNWC09 t7*, P27C08 t6, P27C16 t12, P27C27 t21, PCAXTR t1, PCAXTRKM t1
Low over the northern or central part of the domain	EZ850C10 t3, LUNDC18 t15, LUNDC27 t15, NNWC09 t8, NNWC18 t18, PCAXTRKM t10, SANDRAS t19*
High over the northern or north-eastern part of the domain, eastern flow	CKMEANSCO9 t1, CKMEANSC18 t6, ESLPC09 t4, ESLPC18 t5, ESLPC18 t15, ESLPC27 t12, EZ850C20 t8*, EZ850C20 t11, LUND t4, LUNDC09 t4, LWT2C10 t2, LWT2C10 t7*, PCACAC09 t8, PCACAC27 t15, PCAXTRC18 t12, SANDRA t4, SANDRAC09 t3, SANDRAC18 t18, SANDRAC27 t14, SANDRASC09 t1, SANDRASC27 t7, TPCAC18 t6
Low over the western side of the domain, southern flow	CKMEANSC27 t13, LITTC t11, PCACAC18 t18, PCACAC27 t20, PECZELY t4, PETISCO t18, PETISCOC09 t1, PETISCOC18 t2, PETISCOC27 t2, SANDRASC27 t8
High over eastern side of the domain, southern flow	LITC18 t8*, PCACAC09 t5, PCACAC27 t27, PCAXTRKMC09 t4, PCAXTRKMC18 t6, TPCAC27 t2, TPCAC27 t23

If the types that belong to the first class prevail, there are anticyclonic conditions in the Baltic Sea region. In the winter season this means radiative cooling and the inflow of cold air masses from the east or south-east. The decrease in southern inflow means that there is a lower frequency of the types that carry strong snowfalls in the winter. Those circulation types that have a low pressure area in the central or northern part of the domain, can be related to the cyclones that move from west to east in the southern part of the domain and that also bring along strong snowfalls in the Baltic Sea region.

The types with a positive shift could not be grouped using the K-means method and they are analysed together in Tab. 5.5. The majority of these types are related to a western flow.

The difference lies in the position of the relative centre of the low pressure area – east or west. For some a strong high pressure area dominates in the southern or south-western part of the domain, but in the Baltic Sea region, the western flow prevails. This, however, means a relatively warmer air masses' inflow from the ocean in the winter.

Table 5.5: The circulation types with a positive regime shift in the winter of 1989.

Western flow	CKMEANSC18 t16, ESLPC09 t9, ESLPC18 t11, ESLPC18 t14, EZ850C30 t14, EZ850C30 t29, GWT t1, GWTC10 t1, GWTC18 t1, GWTC26 t2, KHC09 t2, KHC09 t6, KHC27 t10, KHC27 t23, LITC18 t15, LITTC t19, LITTC t22, LUNDC18 t16, LUNDC27 t1, LUNDC27 t16, LWT2 t17, NNW t1, NNW t4, NNW t8, NNWC09 t6, NNWC18 t3, NNWC27 t3, OGWLSLP t1, P27 t26, PCACA t2, PCACA t3, PCACAC09 t2, PCACAC18 t15, PCACAC27 t19, PCACAC27 t21 PCAXTR t9, PCAXTRC09 t8, PCAXTRC18 t1, PCAXTRC18 t7, PCAXTRC18 t14, PCAXTRKMC09 t1, PCAXTRKMC18 t1, PECZELY t12, PETISCO t5, PETISCO18 t8, SANDRA t15, SANDRA t18, SANDRAC18 t3, SANDRAC27 t12, SANDRAC27 t16, SANDRASC18 t5, SCHUEEPP t4, SCHUEEPP t5, ZAMG t17, WLKC09 t8, WLKC18 t17
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5.1.7.4 Summary and Conclusions

Regardless of the presence or not of significant trends in the circulation types of catalogue 1.2, several interesting tendencies were detected using Rodionov's regime shift algorithm. A rapid change in the frequency of circulation types was found for 1989, and especially in winter. This shift (either positive or negative) concerned circulation types with similar characteristics: the types related to very cold winters (types that bring along anticyclonic conditions in the Baltic Sea region with the inflow of cold air from the east or south-east) and the types that bring along heavy snowfall have decreased, while the types associated with relatively warmer air masses from above the ocean became more frequent in winter.

5.1.7.5 Recommendations

- **Family of algorithms**

PCA and LEAD methods generated circulation types where a regime shift was detected in winter 1989, while subjective, non-scalable and THRE-based classifications tended to generate circulation types with fewer detected shifts. At the same time there occurred a seasonal difference – the two last mentioned classification methods were especially well represented in the annual sums.

- **Number of classes**

The number of classes does not have a high impact, because the regime shift occurred mostly in the similar types of the different classifications. This means that we cannot generally determine if there were more types with a regime shift in the classifications that had more types.

5.1.8 Seasonal variations in the frequency of atmospheric circulation types in European regions

Author: Monika Cahynová

5.1.8.1 Introduction

Atmospheric circulation in the northern mid-latitudes exhibits distinct seasonal variations. These seasonal features should be reproduced in the annual cycle of the relative frequency of circulation types (CTs). We propose several new indices to study the seasonal variations of daily atmospheric CTs in the COST733 database of objective and subjective classifications in Europe and 11 European regions.

5.1.8.2 Data and Methods

Circulation classifications from the COST733CAT version 1.2 were used. We have studied the 49 objective classifications employed over all the 12 spatial domains, while the 6 subjective (HBGWL, HBGWT, PECZELY, PERRET, SCHUEEPP, ZAMG) and the 2 objective unscalable ones (OGWL, OGWLSLP) refer to various parts of Central Europe. The original versions of the classifications (those not optimized for a predefined number of CTs) and the NNW classification were not used.

Seasonality indices proposed by CAHYNOVÁ and HUTH (2010b) can be used to study the annual cycle in the relative frequency of circulation types, and can serve as a simple tool for the comparison of different circulation classifications. Their application only makes sense for classifications based on the whole year; for seasonal classifications the indices are not applicable. All the indices are based on the long-term monthly relative frequency of individual circulation types. For each type we indicate the months with the highest and the lowest relative frequency and calculate their difference (range, seasonality).

- “Average seasonality index” – is an average of the seasonality of all types within a given classification. It is strongly anti-correlated with the number of types – the higher the number of types, the lower the average seasonality index.
- “Maximum seasonality index” – is the seasonality of the most seasonal circulation type (that is, the type with the most pronounced annual course). This index can remove the dependence on the number of circulation types in some of the classifications, while in others the most seasonal type can split into two or more types in the same classification with a higher number of types (e.g. the westerly type splits into westerly cyclonic and anticyclonic, thus the value of maximum seasonality index is not retained).
- “Weighted seasonality index” – is also partly related to the number of types, but it takes into account all CTs instead of just the extreme one. The seasonality of each CT is weighted (multiplied) by its relative frequency. The index – sum of weighted seasonality of all CTs – ranges from 0 to 1.

All the indices can be applied on months in individual years instead of long-term monthly values. This way we can construct a time series of seasonality indices. The

correlation of seasonality time series between several pairs of classifications reveals how well they correspond to each other and if they describe the natural interannual variations of seasonality.

5.1.8.3 Results

Long-term maximum seasonality index is displayed in Fig. 5.23. This index ranges from 3% (LITADVE, LITC18, LITTC) to over 80% (ESLPC09, LUND, TPCAC09). The highest seasonality is generally found in the eastern Mediterranean (D11) and the whole Europe (D00), the lowest over Iceland (D01), Scandinavia (D02), British Isles (D04), and the Baltic region (D05). The seasonality of the unscalable (subjective and objectivized) catalogues is mostly lower than the average of the scalable ones in a comparable region of Central Europe (D07). LUND, PCAXTRKM, PETISCO, and TPCAC09 catalogues bear the highest spatial variation of seasonality. Maximum seasonality index decreases with increasing number of CTs in some classifications (Fig. 5.23); others retain almost the same values for all the three variants with 9, 18, and 27 CTs (most notably in LUND). We can see in Fig. 5.24 that the relative frequency of the most seasonal CT decreases with increasing number of CTs with the exception of LUND.

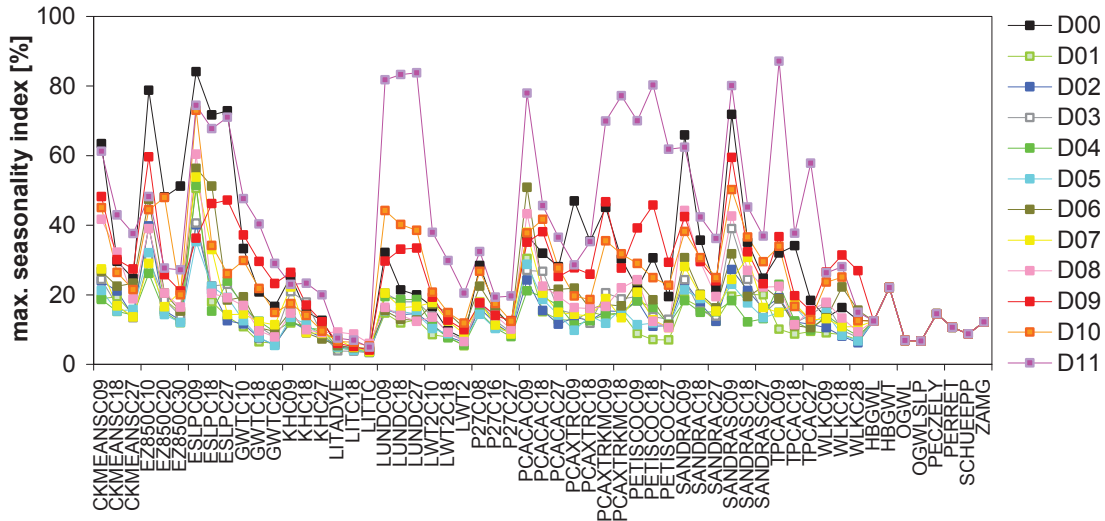


Figure 5.23: Maximum seasonality index – long-term seasonality of the most extreme CT. Colours denote spatial domains. The unscalable classifications do not pertain to any fixed domain.

The average seasonality index (averaged seasonality of all CTs, not shown) is highly dependent on the number of CTs. Its values are much lower than those of maximum seasonality index, from 2% to 36%. On the other hand, the weighted seasonality index takes into account the overall seasonality of all CTs with respect to their relative frequency. Its values are usually a bit lower (or noticeably lower for some classifications) than the maximum seasonality index (not shown).

For the objective scalable classifications we have constructed time series of maximum seasonality index by calculating it separately for every year (years starting in December to include the whole winter). The maximum seasonality index averaged over all years (26% to 94%, not shown) is much higher than the same index calculated from the long-term monthly relative frequency of CTs (Fig. 5.23). This is due to the fact that in the

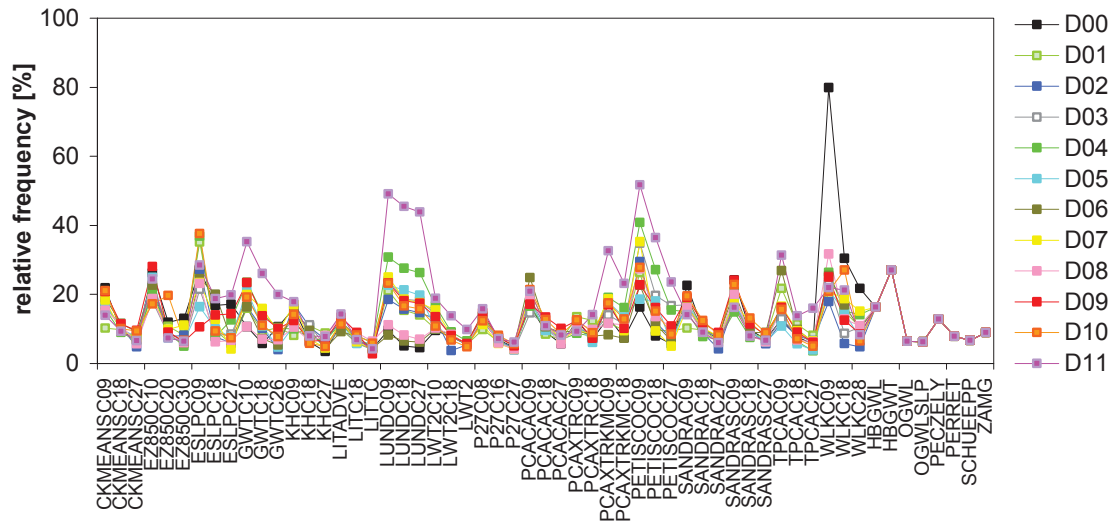


Figure 5.24: Long-term relative frequency of the CT with the highest seasonality.

individual years different CTs can act as the most seasonal ones, while in the long term only one CT is taken into consideration.

Long-term trends of annual maximum seasonality index are rarely significant at the 95% level; both positive and negative trends occur even in the same spatial domain. The Pearson correlation of maximum seasonality index time series of all pairs of classifications is significant at the 95% level only in 15% to 47% of cases in different spatial domains. The lowest number of significant correlations is found in the eastern and western Mediterranean (D11, D09) and over the whole Europe (D00); the highest number is in northeastern Europe (D03), over Iceland (D01), and Scandinavia (D02). Fig. 5.25 shows the average correlation of the given classification's time series with that of all other classifications. Despite the statistical irrelevance of average correlation we still can see some systematic differences between classifications. CKMEANS and SANDRA correspond the most with the other classifications. EZ850 and WLK are least connected to the other ones, often yielding negative values of the correlation coefficient.

5.1.8.4 Summary and Conclusions

Seasonality is one of the basic properties of atmospheric circulation in the northern mid-latitudes. Not surprisingly, seasonality of the occurrence of circulation types varies throughout the European regions, being the highest in the southeast and the lowest in the north and west. There are large systematic differences in the seasonality between the individual classifications; it is thus impossible to discern the natural seasonal variations from the artificial effect of the classification method. The temporal evolution of annual maximum seasonality index is very heterogeneous when comparing the classifications with each other. The classifications the least connected to all other ones are WLK and EZ850, while CKMEANS and SANDRA are the best ones.

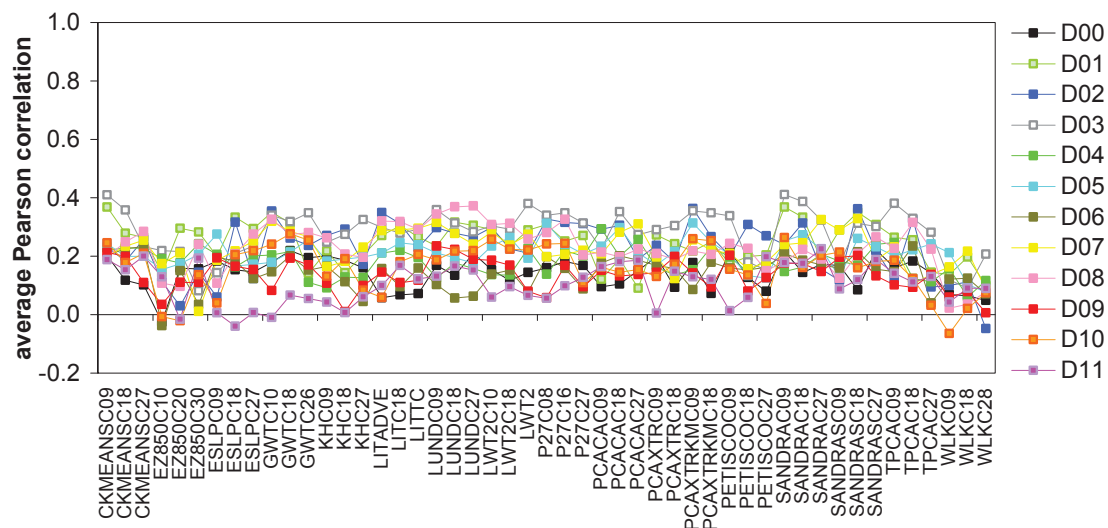


Figure 5.25: Maximum seasonality index time series – average Pearson correlation of the given classification's time series with all the other objective classifications.

5.1.8.5 Recommendations

No recommendations regarding the methods and variants of circulation classifications, since this analysis does not aim at comparing them according to their performance. We strongly recommend the use of more parallel classifications even for such basic analyses of atmospheric circulation, as the individual catalogues are by no means representative.

5.1.9 Long-term trends in the frequency and persistence of atmospheric circulation types in European regions

Author: Monika Cahynová

5.1.9.1 Introduction

Circulation changes are a crucial part of the climate system that can both reflect and affect local climatic trends. Here we study the changes in the seasonal occurrence and persistence of circulation types in European regions in many objective (automated) and subjective classifications from the COST733 database in the ERA-40 period (9/1957–8/2002). This comparative approach allows us to distinguish real circulation changes from those caused by manual synoptic classification, such as the mid-1980s enhancement of persistence in the Hess-Brezowsky catalogue that has been previously attributed to a systematic change of the circulation itself (WERNER et al., 2000). More information can be found in CAHYNOVÁ and HUTH (2009).

5.1.9.2 Data and Methods

All objective and subjective circulation classifications from the COST733CAT version 1.2 were used. We have studied the objective classifications employed over all the 12 spatial domains, while the subjective and the unscalable objective ones refer to various parts of Central Europe. Seasonal circulation trends in the period 1957–2002 were estimated using linear least-squares regression applied to the seasonal occurrence of days with a specific circulation type (CT), and to the average seasonal persistence (lifetime) of CTs. The common t-test was performed to evaluate the statistical significance of trends.

5.1.9.3 Results

In the 65 objective scalable catalogues the proportion of days occupied by CTs with trends in seasonal frequency significant at the 95% level is mostly very low except for Central and Eastern Europe (domains 07 and 08) in winter and the Mediterranean domains 06, 10, and 11 in winter and summer (see Fig. 5.26). Generally, the magnitude of trends is the highest in winter. In the Mediterranean domains the significant trends of frequency usually occur in the prevailing (most common) CTs in summer, whereas in other seasons and regions there is no such preference.

The six studied subjective catalogues contain a substantial proportion of CTs with significant trends in frequency in all seasons; also the trend magnitudes are larger. Whether these long-term trends in the subjective catalogues reflect real climatic changes or result from manual data evaluation is still an open question.

Seasonal trends in the persistence of all CTs combined are mostly insignificant in the objective catalogues; therefore the recently reported enhancement of persistence in the subjective Hess-Brezowsky in the mid-1980s (see Fig. 5.27) is rather an inhomogeneity than a real change of the circulation regime. Individual CTs in the objective catalogues bear both positive and negative trends (their numbers being comparable), whereas the Hess-Brezowsky CTs underwent notable positive trends in persistence. The subjective Hungarian PECZELY catalogue shows a decrease in persistence in 1985/86, coinciding with the opposite shift to higher values in the Hess-Brezowsky. We have further used

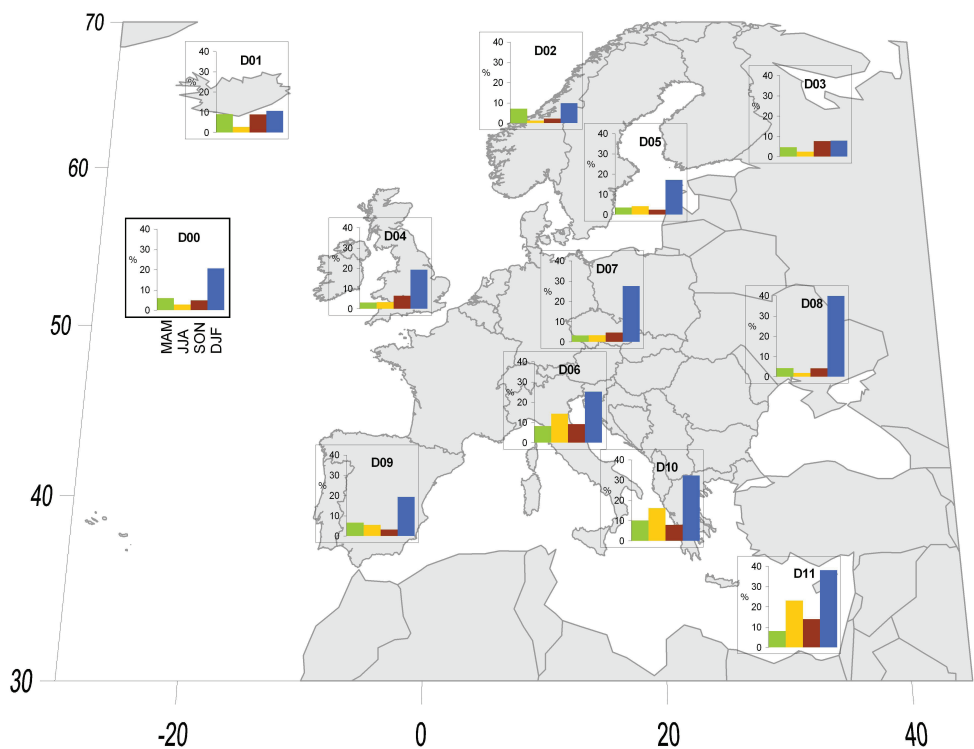


Figure 5.26: Seasonal percentage of days contained in circulation types with significant linear trend in frequency (at the 95% level). Average of all objective scalable classifications.

three versions of an “objectivized” Hess-Brezowsky classification for a direct comparison (OGWL, OGWLSLP from COST733CAT. 1.2, and OGWL-3d+ with an induced minimum 3-day persistence of CTs provided by Paul James). Neither of these has shown a significant trend or shift in the persistence of CTs.

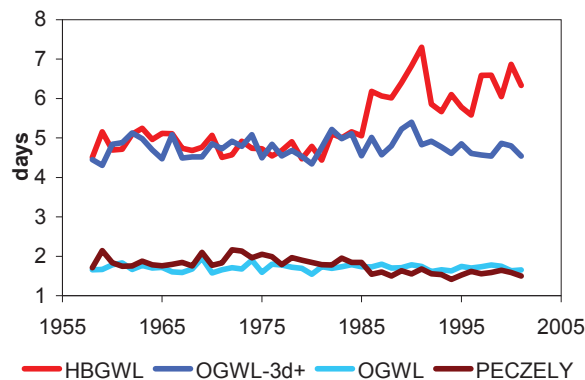


Figure 5.27: Average annual persistence of all circulation types combined. HBGWL = Hess-Brezowsky, OGWL-3d+ = objectivized Hess-B. with a minimum 3-day duration of types.

5.1.9.4 Summary and Conclusions

Seasonal linear trends in the frequency and persistence of CTs were studied in classifications from COST733CAT version 1.2, in all the spatial domains, in the period 1957–2002.

The total number of individual CTs was >55,000. Because of the different relative frequency of individual CTs, we have calculated the percentage of days occupied by CTs that have a significant trend in seasonal frequency. This proportion is mostly very low except for Central and Eastern Europe in winter and the Mediterranean in winter and summer, which suggests that apart from the winter intensification of the NAO, very few “systematic” changes in circulation took place over Europe in the study period.

The sudden changes of persistence (lifetime) of CTs in two subjective catalogues – German Hess-Brezowsky and in Hungarian PECZELY – that both occurred in 1985/86 was not found in any of the objective catalogues. The overall persistence of synoptic situations has not changed in any season according to the objective catalogues.

5.1.9.5 Recommendations

No recommendations regarding the objective catalogues, since this analysis does not aim at comparing them according to their performance. The subjective catalogues HBGWL (HBGWT) and PECZELY most probably contain inhomogeneities that are reflected by sudden shifts in the persistence of CTs. We therefore recommend a cautious use of these catalogues, even though they may outperform the objective ones in their better representation of local weather and climate.

5.1.10 Real-time precipitation analysis using information on spatial covariance and circulation type

Authors: Reinhard Schiemann, Christoph Frei and Mark A. Liniger

5.1.10.1 Introduction

There is an obvious need for quantitative and spatially resolved information on precipitation in applications such as runoff forecasting, water resources management, and avalanche warning systems. In Switzerland, the climatological rain-gauge network is very dense and serves many applications with high-resolution data of the past. Yet, only a rather small part of the gauges can provide measurements on a real-time basis and in an automated fashion. Most of the observations are taken manually and typically become available with a delay of some days or weeks. Therefore, gridding methods have to rely on a coarse network of stations when applied in a real-time context, which may severely limit the quality of interpolated analyses.

In this study, we investigate a method for improving the quality of near real-time spatial analysis of daily precipitation from a sparse gauge network. To this end, the nested application of two approaches is investigated (SCHIEMANN *et al.*, 2010). Firstly, in addition to the observations from the sparse network, we incorporate information on the spatial covariance in the daily precipitation fields determined from high-resolution measurements of the past. In a mountainous region, precipitation patterns have a strongly convoluted spatial structure (e.g. DORNINGER *et al.*, 2008; HOFSTRA *et al.*, 2008), which is hardly resolved by real-time rain-gauge networks, but could be estimated from past data. Secondly, we introduce information on the large-scale atmospheric circulation in the form of circulation types (CTs). Precipitation patterns are recurrent in time due to characteristic orographic forcing in situations with similar large-scale atmospheric circulation. Consequently, it appears promising to test, for the territory of Switzerland, if the gridding performance improves if information on the large-scale atmospheric flow is explicitly taken into account in terms of CTs.

Several authors have exploited CT information for mesoscale precipitation analysis. For example, COURAULT and MONESTIEZ (1999) have determined CT dependent lapse rates and semivariograms in an ordinary kriging, TVEITO (2002) uses CT stratification in the deterministic component of a gridding scheme, and HEWITSON and CRANE (2005) have modified the classical Shepard approach (SHEPARD, 1968, 1984; RUDOLF *et al.*, 1992) by introducing CT dependent station weights. Herein, we follow these ideas and stratify the spatial analysis with respect to the types of two classifications of the circulation in Central Europe.

5.1.10.2 Method and data

The method we use is reduced-space optimal interpolation (RSOI KAPLAN *et al.*, 1997). Previous applications of this technique have been concerned with the reconstruction of global historical monthly sea surface temperatures, night marine air temperature, and sea ice (KAPLAN *et al.*, 1998; RAYNER *et al.*, 2003), of monthly marine and global mean sea level pressure (KAPLAN *et al.*, 2000; ALLAN and ANSELL, 2006), of daily mean sea level pressure for the European-North Atlantic region (ANSELL *et al.*, 2006), of Pacific sea surface temperatures from proxy data (EVANS *et al.*, 2002), and of monthly precipitation

in the Alps (SCHMIDLI et al., 2001, 2002). To the knowledge of the authors, this is the first study to test the feasibility of reconstructing daily, i.e. strongly skewed, precipitation data by means of RSOI. While the above studies are concerned with the reconstruction of historical climate data, the idea behind this study is a near real-time application of RSOI where the reconstruction period corresponds to a “very recent past”.

The optimal interpolation technique exploits the statistical relationship between the coarse real-time and the dense climatic networks. It consists of two main parts. First, principal component analysis is used to obtain a reduced-space description of the high-resolution precipitation data during a calibration period. Second, data from the low-density real-time rain-gauge network are used to estimate the scores of the leading principal components in the reconstruction period. In this way, the method considers both the temporal evolution of the precipitation field during the reconstruction period and the spatial covariance structure that is known from the long-term high-resolution climatology. A detailed description of the method and its present application is provided in SCHIEMANN et al. (2010).

The domain considered in this study is Switzerland (Fig. 5.28 a). We define two networks of rain gauges. The red dots show a dense network of gauges with typically 420 precipitation totals available on individual days. This corresponds to a median nearest neighbour distance of ≈ 5 km. Furthermore, an ad-hoc choice of a sparse network is shown by the blue circles. It has 51 gauges and a median nearest-neighbour distance of ≈ 20 km. The dense network data have been used for the construction of daily precipitation grids by means of a modified SYMAP algorithm as described in FREI and SCHÄR (1998) and (FREI et al., 2006, section 4). The grids obtained in this way are available through 1960–2007. They are provided at a resolution of $\approx 2 \times 2$ km and their effective spatial resolution is $\approx 15 \times 15$ km (METEOSWISS, 2006; FREI et al., 2006). These fields are the best estimate of the daily precipitation distribution in Switzerland that we currently dispose of. We attempt to reproduce these fields as closely as possible and therefore refer to them as the *observations* (OBS). The long-term mean of OBS is shown in Fig. 5.28 b.

Furthermore, we consider daily precipitation grids constructed from the sparse network (51 instead of 420 stations) in terms of two different interpolation methods. These methods are (i) reduced-space optimal interpolation whose application is the focus of this study and incorporates the spatial covariance structure of the OBS data, and (ii) the modified SYMAP algorithm, which is used as a reference method (and is the same method used to construct the OBS fields from the dense network). The corresponding grids are referred to as RSOI and SIMPLE, respectively, and are evaluated by quantifying their agreement with OBS.

Finally, we test if the RSOI skill improves when the method is calibrated only with days of the same weather type as the day for which the reconstruction is carried out (*stratified* application of RSOI; see SCHIEMANN et al., 2010, for details). To this end, two classifications from version 1.1 of the COST733 catalogue of CT classifications (PHILIPP et al., 2010) are used: the PCACA classification (RASILLA ÁLVAREZ, 2003; GARCÍA CODRON and RASILLA ÁLVAREZ, 2006) distinguishing 5 CTs and the SANDRA classification (PHILIPP, 2007) with 22 types.

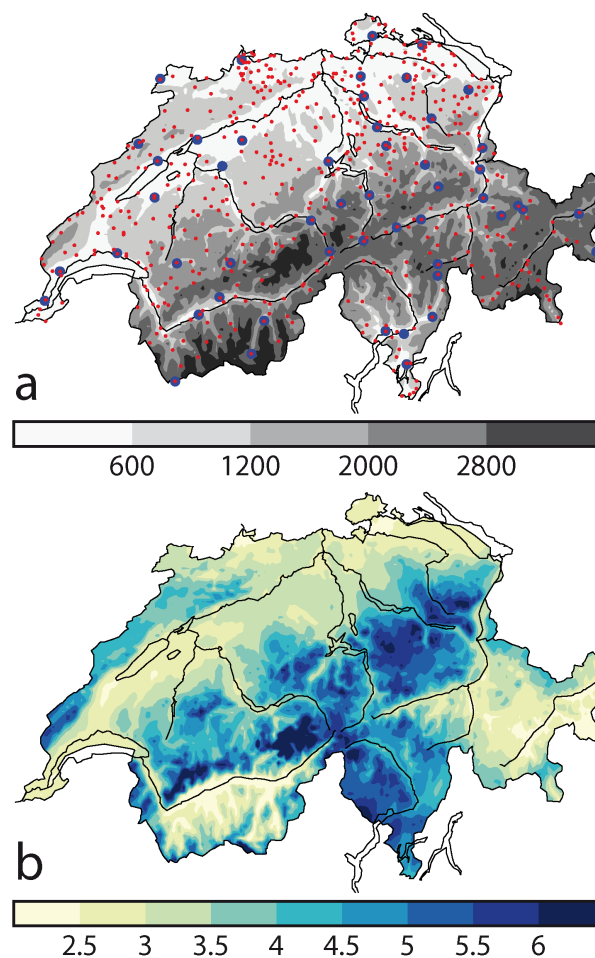


Figure 5.28: Overview of the study area. (a) Gauges of the sparse network (51 stations; blue circles), the dense network (typically 420 stations on individual days; red dots) and height of topography (shading). (b) Long term mean precipitation (mm d⁻¹).

5.1.10.3 Conclusions

RSOI is a statistical procedure which allows reconstructing daily precipitation fields from measurements of sparse station networks. It is inherent to RSOI that it yields spatially smoothed precipitation fields. Nevertheless, gridding in terms of RSOI clearly outperforms the SIMPLE reference interpolation method (based on contemporaneous gauge data only) for the study domain and the networks considered herein (Fig. 5.29). The improvement over the reference method is particularly strong for locations at greater distance from the gauge locations. Consequently, RSOI lends itself to gridding in a quasi real-time context, when only measurements of a small part of the full gauge network are available. In fact, MeteoSwiss has started using RSOI to operationally derive a preliminary spatial precipitation analysis for the previous day (with a slightly denser real-time network than the one used in this feasibility study). The interpolation presented herein is entirely based on gauge measurements and their covariance in space; it does not use other sources of data such as radar measurements (e.g. [GJERTSEN et al., 2004](#); [DEGAETANO and WILKS, 2009](#)). Thus, RSOI is attractive as a reference for methods using additional data sources, or in situations when no additional data are available.

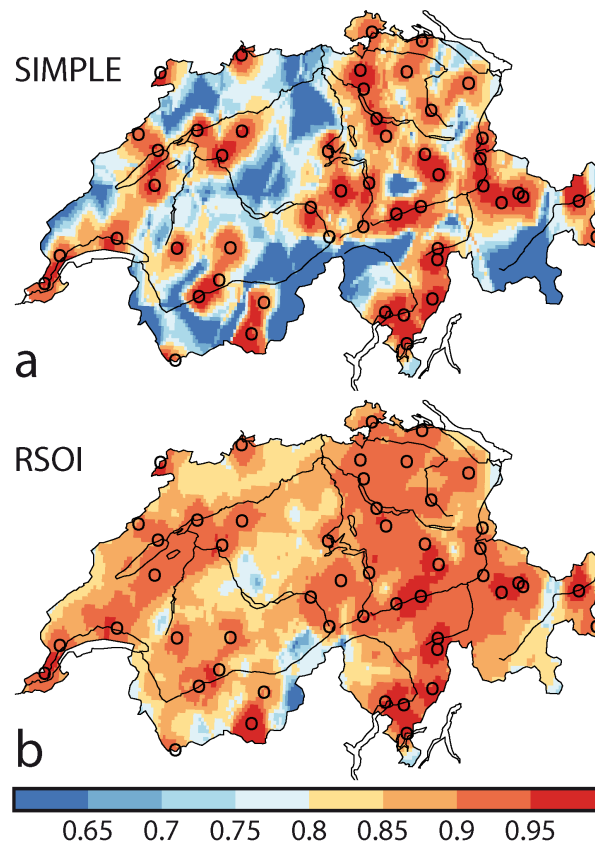


Figure 5.29: Mean squared error skill score (MSESS) of interpolated precipitation maps at each grid point. (a) SIMPLE, (b) RSOI. Circles show the locations of gauges in the sparse network.

Table 5.6: Median mean-squared error skill score (MSESS) for days of the five CTs of the PCACA classification, for unstratified RSOI (top row) and RSOI stratified with respect to the circulation type (2nd row). The mean daily Swiss precipitation for each CT is also shown.

	<i>CT1</i>	<i>CT2</i>	<i>CT3</i>	<i>CT4</i>	<i>CT5</i>
MSESS (unstratified)	0.717	0.817	0.841	0.689	0.845
MSESS (stratified)	0.709	0.826	0.857	0.693	0.856
mean precipitation (mm d ⁻¹)	1.2	7.1	6.5	2.3	5.3

It has been shown that the improvement due to the inclusion of weather type information is comparatively small and depends strongly on the weather type. Stratification is generally more beneficial for wet weather types than for dry types (Tab. 5.6). Arguably, the following two reasons explain this finding: first, the estimation of the scores of the leading principal components of the precipitation field is an integral part of RSOI. These leading scores inherently contain information on the CT and an explicit stratification with respect to CTs appears to add only relatively little extra information. Second, there is indication that the reduction in sample size associated with the stratification may offset the potential benefits from circulation-type information.

5.1.10.4 Recommendation

CT information can – in principle – be introduced in procedures of spatial interpolation, via stratification of the underlying statistical relationships and parameters. The added value that can be expected from such a procedure depends on how complementary CT information is to other input data (notably the station data), and on how strong the relationship is between circulation and the field of interest. Moreover, the stratification can introduce sampling uncertainties which could (partly) offset the gain from the CT information. Even though the added value was minor in the application studied, the understanding we gained from this exercise suggests: Incorporation of CT information in spatial analysis is worth being tested in areas where station density is very sparse, in combination with more simple interpolation methods (e.g. those not exploiting covariance structures from past data), with meteorological parameters that have a stronger (less variable) relationship to circulation than precipitation (e.g. pressure, possibly temperature and sunshine duration), and when the interest is on specific conditions with a known signal. Care should be exercised when using CT classifications with a large number of types. A long calibration period might be important to avoid sampling uncertainty in such applications.

5.1.11 Conclusions and recommendations – subgroup “Climatology”

The case studies clustered in the climatology subgroup addressed a very broad number of applications and different space and time scales. Hence, this makes almost impossible to unify the results and bring forward generic recommendations. Nevertheless, 4 general remarks should be considered in the further use of circulation type classifications:

- (1) It is important to consider more parallel classification methodologies, as individual catalogues are by no means representative,
- (2) the subjective catalogues HBGWL and PECZELY should be used with caution, as they most probably contain inhomogeneities that are reflected by a sudden shift in the persistence of some circulation types,
- (3) any of the classifications nor any family of algorithms is found to systematically have the strongest/weakest links with any of the considered applications, and
- (4) the ideal number of classes is actually very linked to the considered application and dependent on the choice of the evaluation metric.

Tab. 5.7 presents a summary of the main results and recommendations.

Table 5.7: Summary of the results from the case studies in the subgroup “climatology”. The symbols refer to: (1) – –/++: A lower/higher number of classes improve the results; (2) +/-: improvement/deterioration of the results; (3) ≈: no conclusive evidence for a significant impact and (4) blank: This criterion is not tested. *) results here depend on the choice of evaluation metric. **) Results here depend on the region.

<i>Cat. version</i>	<i>Variable tested</i>	<i>Preferred algorithm (class)</i>	<i>Preferred domain (domain of interest)</i>	<i>nr. of classes</i>	<i>Addt'l. input variable</i>	<i>Seasonal ?</i>	<i>Sequence ?</i>
2.0	Wind	LDR, OPT	D10 (Slovenia)	++	+	–	
1.2 & 2.0	NAO+ NAO–	OPT/OPT- PCA	D00 (Spain)	++	–	≈	– except KRZ
1.2 & 2.0	Precipit.	OPT/ THR**)	D09 (Spain)	–*)	+	≈	–
1.2	Temperat. and precip.	≈	Small ones	++			

5.2 Applications in Air Quality

Since the last decades, several studies focused on the relationship between air pollution and synoptic circulation patterns. Hereby, circulation patterns are derived for a specific time and region of interest from different predictor variables (e.g. SLP, 850 hPa, wind direction and intensity, forward or backward air mass trajectories...) and are used afterwards as an indicator of high air pollution episodes and long range transport of pollutants. Thereby, a large number of studies relate these large-scale synoptic patterns to mean levels of surface O₃ (e.g. [SCHJOLDAGER, 1981](#); [VAN DOP et al., 1987](#)), whereby an attempt is done to mark these findings in relation to the associated meteorological characteristics. For example, regimes with high pressure systems associated with high temperatures and low wind speeds are common on days with high ozone (mixing) ratios ([HOGREFE et al., 2004](#); [AINSLIE and STEYN, 2007](#)). Others have shown that low wind speeds are an important element characterizing high ozone episodes (e.g. [KASSOMENOS et al., 1998](#); [AINSLIE and STEYN, 2007](#)). The former classified eleven distinct mesoscale patterns derived from 850 hPa levels by analyzing meteorological sources gathered between 1983–1995 over Athens (Greece) and found that severe and bad air quality conditions were highly related to southerly sea breeze and calm wind. The latter performed a cluster analysis of wind measurements in the Lower Fraser Valley, British Columbia (Canada), to identify mesoscale circulation regimes that are common on days with high ozone mixing ratios. In fact, the meteorology (air mass characteristics: wind speeds, turbulence, vertical mixing, inversions, etc), determined by air circulation patterns causes more or less effective dilution of the emitted pollutants and thus the daily fluctuation of the concentrations.

These are just some examples of the use of circulation patterns in air quality research. And although [DEMUZERE et al. \(2009a\)](#) pointed out that the direct use of circulation patterns as e.g. a forecast tool for O₃ and PM₁₀ is rather limited (compared to e.g. a linear multiple regression approach), the authors do point out that the use of such a large-scale synoptic approach still holds a degree of physical meaning in terms of peak air quality episodes. Furthermore, it is important to mention that previous studies have also addressed the use of circulation patterns on other chemical compounds. Nevertheless, this is not further elaborated here, as the contributions of the different members of the air quality subgroup primarily focus on O₃ and particulate matter (PM) in the following case studies:

- Surface ozone related to circulation patterns in Poland (cf. Subsection [5.2.1](#)).
- Relations between circulation and winter air pollution in Polish urban areas (cf. Subsection [5.2.2](#)).
- Relations between circulation and summer ozone concentration in different European locations (cf. Subsection [5.2.3](#)).
- Spectral analysis of total suspended particles in connection with circulation patterns in the central and eastern part of Europe (cf. Subsection [5.2.4](#)).
- The explanatory power of circulation patterns on surface ozone concentrations in Central Europe (cf. Subsection [5.2.5](#)).

Hence, this overview shows a possible capability of circulation patterns with their associated meteorological characteristics to discriminate between low and high concentrations of especially ozone and suspended particles at a large number of sites across Europe.

5.2.1 Surface ozone related to circulation patterns in Poland

Author: Magdalena Bogucka

5.2.1.1 Introduction

One of the objectives of the COST Action 733 is to find a (the) best classification(s) of weather/circulation types which is (are) able to split meteorological related parameters in the best way. The most important task is to state the definition of a good classification and perform the analyses to find the better one (ones). According to [BARDOSSY \(2008\)](#) a good classification should be: (1) objective – reproducible, (2) based on the primary variable, (3) classes should show different behaviour with respect to the variables of interest, (4) should not have too many classes, (5) all classes should be frequent enough, and (6) capture anomalies, e.g. wet/dry years (seasons, months, and days).

This study will apply the circulation patterns as developed within the COST733 action on surface ozone concentrations. This chemical pollutant has become a significant concern due to its toxicity and negative influence on human health and vegetation. As a secondary pollutant, ozone in the troposphere is produced from other pollutants and its concentration in the air depends on weather conditions. This study investigates whether it is possible to categorize and identify weather conditions favourable for ozone pollution using Circulation Types Classifications.

5.2.1.2 Data and Methods

This study is based on COST733CAT 1.2, with some findings obtained by catalogue 1.1, using data from 73 circulation type classifications (CTCs) for 1996–2002, for spring (MAM) and summer (JJA). Surface ozone data from three background air pollution rural stations in Poland were used, representing different geographical conditions: Leba is situated on the seaside of the Baltic Sea; Sniezka (1603 m a.s.l, Sudety) is mountain summit in SE Poland and Jarczew is located in central part of Poland in an agricultural district. Stations are run by the Institute of Meteorology and Water Management, Warsaw, Poland (IMWM) within the framework of EMEP and Global Atmosphere Watch (GAW) programmes. They are located far from local sources and suited to determine the background level of pollutants on the regional scale. Classifications defined over different spatial domains were considered: (i) D00 – Europe, for Leba, Jarczew, Sniezka; (ii) D07 – Central Europe, for Leba, Jarczew, Sniezka, (iii) D05 – Baltic Sea, for Leba, and (iv) D06 – Alpine region, for Sniezka (Fig. 5.30). Two surface ozone data metrics were considered: maximum 8-hourly mean concentrations (8hmax O₃) and days with 8hmax O₃ higher than 120 µg/m³ (8hmax O₃ >120). This threshold is defined as the level above which ozone concentration becomes harmful for human health according to regulatory standards set by the European Union Air Quality Directives ([EU, 2008](#)). As a pre-processing of the data shows that around 90% of ozone exceedances (8hmax

O₃ >120) occur in spring and summer with a remaining 10% in autumn and winter, only spring (MAM) and summer (JJA) seasons have been investigated.

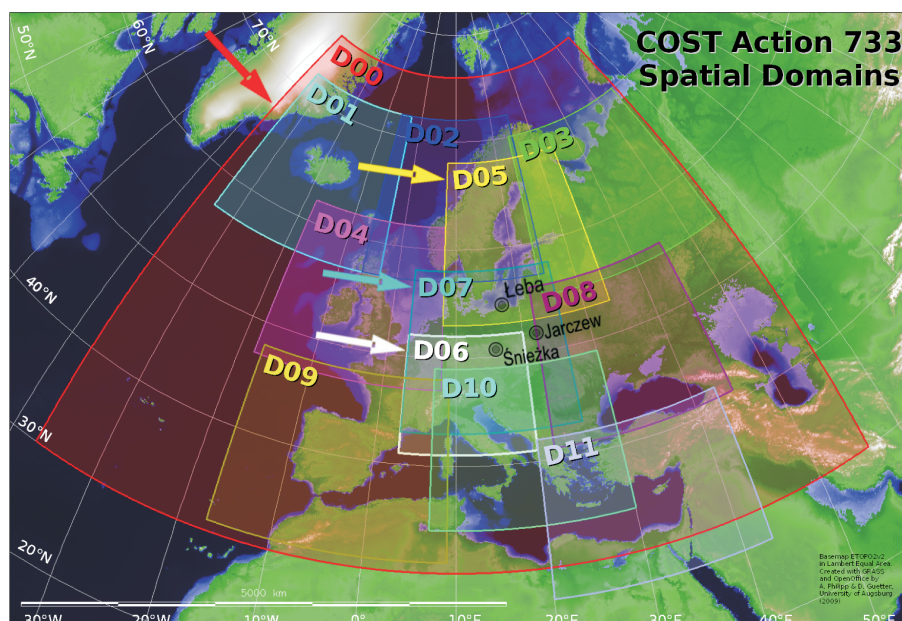


Figure 5.30: Location of Poland's EMEP ozone study stations against domains.

Three indices were considered: (1) Explained Variation (EV); (2) Within-Type Standard Deviation (WSD), and (3) Approach of defining/searching for circulation patterns which bring ozone weather or non-ozone weather into the specified region. In this method some remarks and findings of [BARDOSSY et al. \(2002\)](#) were applied. Here the classifications with classes (circulation patterns) having much more (e.g. 5 days or more) 'high ozone days', i.e. days with 8hmax O₃ >120, than other 'non ozone days' are preferred as the best.

5.2.1.3 Results

The results are summarised for each index in turn (Fig. 5.31a and 5.32).

(1) Explained variation (EV): higher values indicate better classification

With respect to the choice of domains; for 8hmax O₃ domain D07 seem to be better than D00 for all analyzed stations; for spring ozone data from Śnieżka domain D06 performs comparable to domain D07. Furthermore, best results were obtained for 27 classes and for original number of classes. The analysis indicated that for 8hmax O₃ data for rural surface ozone in Poland the best results by EV index, according to cat.1.2 nomenclature, were obtained by the following CTCs: for spring (MAM) – SANDRAS, WLKC733, EZ850C30, HBGWL, OGWL, Perret, but also SANDRASC27, PCACA27, NNW, EZLPC27, EZ850C20; for summer (JJA) – WLKC733, P27, PETISCO, OGWL, HBGWL and ZAMG, but also having more classes (namely 18 and 27) versions of PETISCO, P27, SANDRAC, SANDRAS, WLKC.

(Continued on page 243)

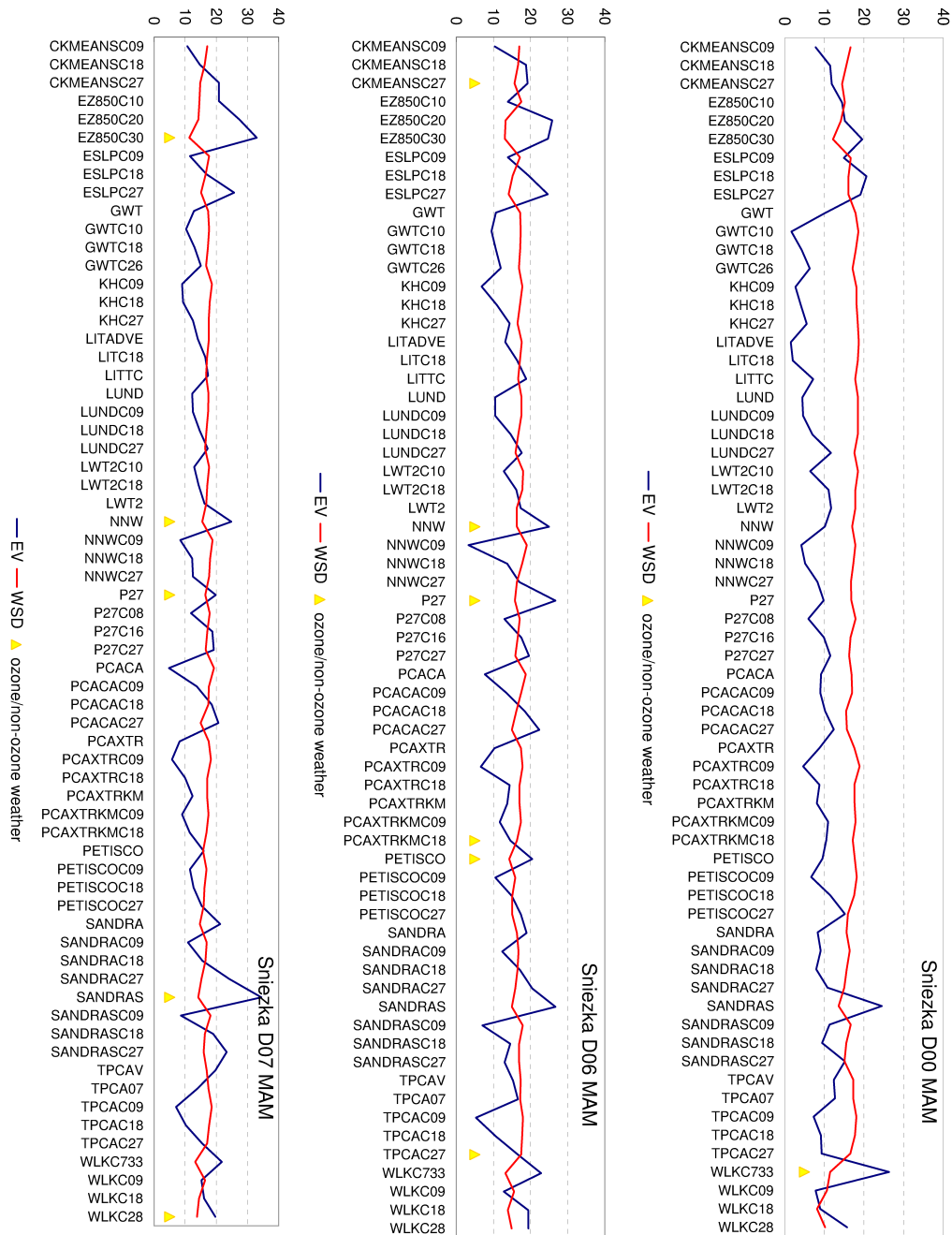


Figure 5.31a: Results for Sniezka (mountain station) for the spring (MAM) season for different COST733 spatial domains (example of evaluation).

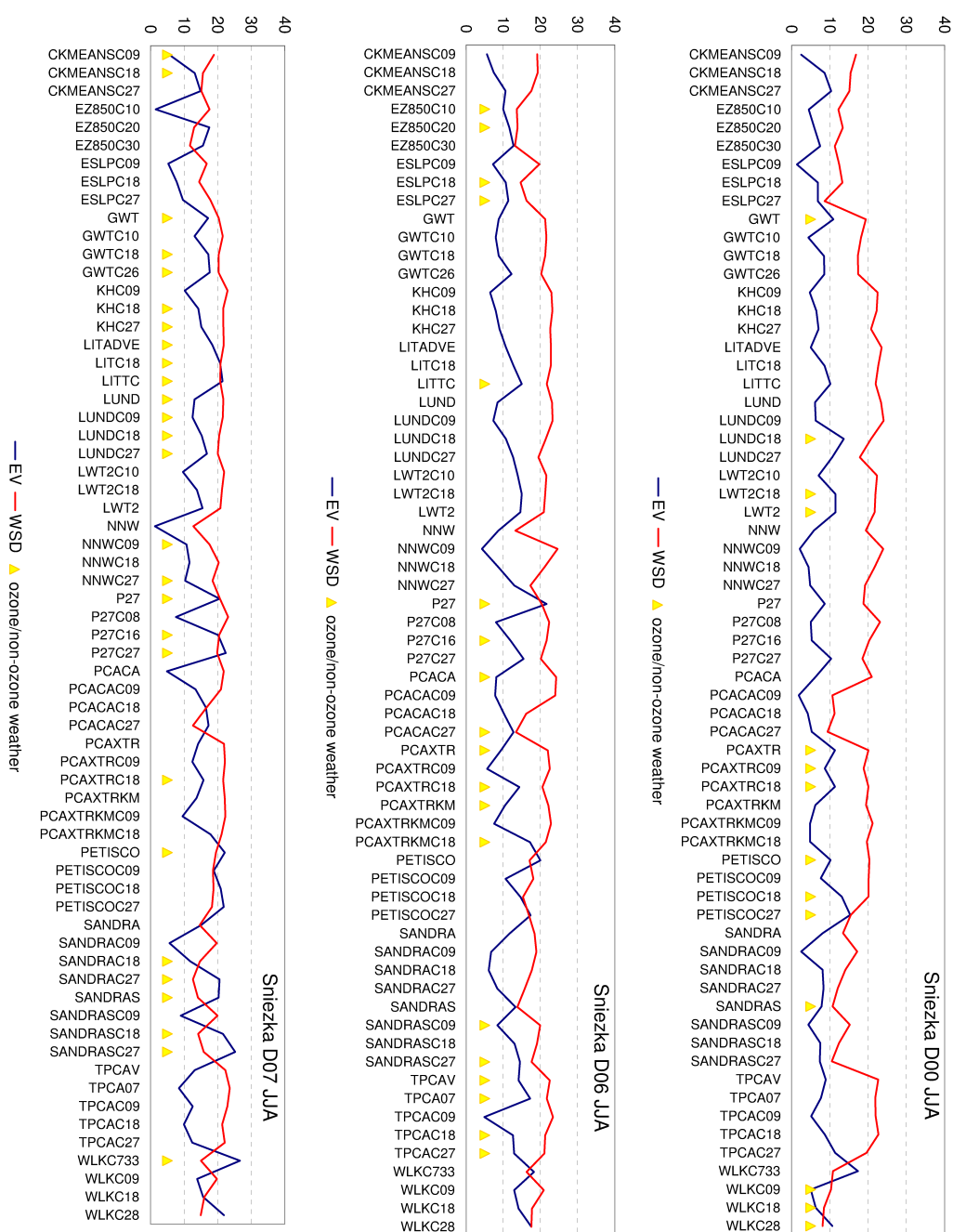


Figure 5.31b: Results for Sniezka (mountain station) for the summer (JJA) season for different COST733 spatial domains (example of evaluation).

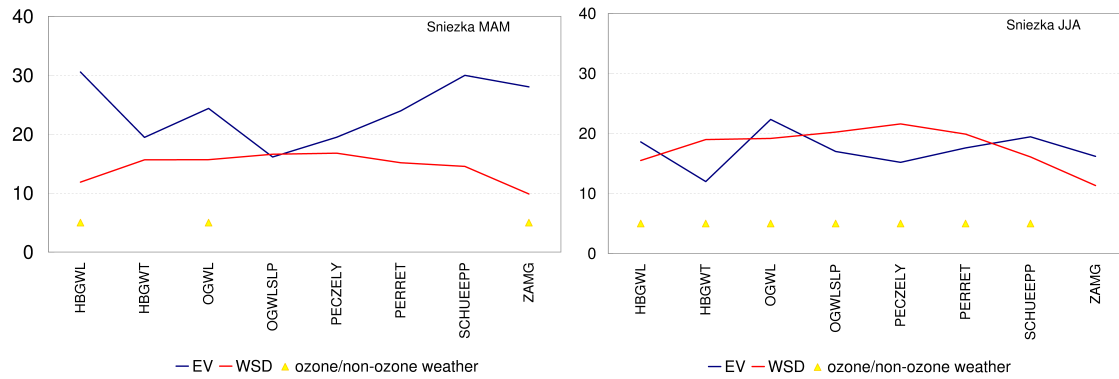


Figure 5.32: Results for Sniezka (mountain station) for spring (MAM, left) and summer (JJA, right) seasons for original (non-scalable) classifications (example of evaluation).

(2) Within-type standard deviation (WSD): lower values of WSD indicate a better classification

Unlike EV, all WSD have similar values for all tested classifications, thus it is difficult to conclude on best method. With respect to the choice of domains, WSD suggests better performance for domain D00 than for D07. This is contrary to the conclusions gained by EV index. WSD gives better results for fewer numbers of classes, which is also opposite to results obtained by EV index. According to the WSD index, the best CTCs are: WLKC18 (28, 09, 733) and ZAMG for both seasons, but also EZ850C30 for spring (MAM), and EZ850C10 (20, 30), ESLPC27, PCACAC09 (27, 18), SANDRAS, and rest of SANDRA classifications for summer months (JJA) (example for Sniezka in Figs. 5.31a and 5.32).

(3) Evaluation measure: Ozone/non ozone weather (1/0)

The explanatory power of the method consists in searching for the classifications having classes (i.e. circulation patterns) with much more ozone days than non-ozone days. The method is best for stations having high number of ozone days, e.g. Sniezka (mountain top). Here, the smaller domains provide better results than D00. For Sniezka (mountain station) D06 (Alpine region) performs better than D07 (Central Europe). With respect to the number of classes, the more classes we have, the better are the results, but only few classes (two or three) are actually related to ozone days. Note here that for most classifications, exceedances in surface ozone in Poland are generally associated with SA (southern anticyclonic) and SWA (south-western anticyclonic) situations.

5.2.1.4 Summary and Conclusions

In general many of the proposed classifications are applicable in order to categorize surface ozone situations in Poland. It is not possible to point out the best ones. The evaluation shows that in many cases better results were obtained by classifications having maximal number of classes (27 or more, like the original CTCs, e.g., Hess-Brezowsky, Schueepp). In general, the original (subjective) classifications, as e.g. HBGWL,

WG 4: *Method testing*

HBGWT, OGWL, OGWLSLP, PECZELY, PERRET, SCHUEEPP and ZAMG show very good results according to all used evaluation methods.

5.2.1.5 Recommendations

- **Family of algorithms**

See above.

- **Domain size and locations**

The use of a smaller domain for the classification of circulation patterns, centred on the domain of interest, is preferred.

5.2.2 Relations between circulation and winter air pollution in Polish urban areas

Authors: Jolanta Godłowska and Anna Monika Tomaszewska

5.2.2.1 Introduction

Urban areas are characterized by both a large heterogeneity of emissions and a spatial variability of roughness. Turbulence induced by merged interactions of temperature, wind and friction causes some homogenization of the air, but physical, chemical and meteorological parameters characterizing air conditions change inside cities (FISHER *et al.*, 2005; PIRINGER and JOFFRE, 2005). Nevertheless, inside a city, the day-by-day variability of different pollutants measured in different places is generally similar, showing the influence of larger scale external factors. As emissions usually don't change quickly with time (except for daily variability), weather conditions connected with air pollution transport and dispersion play the crucial role in changing pollutants concentration (GODŁOWSKA, 2004). Nowadays, transportation and heating systems based on coal burning are the main sources of winter air pollution in Polish urban areas. As these sources of emissions are located near ground level, mainly in urban canopy layer or just above it, meteorological conditions such as wind speed and thermal structure of urban boundary layer play a key role in displacing pollutants outside the city. The inversion of temperature causes the accumulation of pollutants in the lower boundary layer. Moreover, the area accessible for vertical mixing becomes smaller as a result of the blocking caused by the elevated inversions. This reflects the behaviour of air pollution concentrations that are the highest when low-level elevated inversion can be found (GODŁOWSKA *et al.*, 2008). Here, the usefulness of different circulation type classifications for winter urban air pollution using the COST733 catalogues is examined.

5.2.2.2 Data and Methods

The analysis is based on the COST733CAT v1.1 and v1.2 circulation type classifications (CTCs) catalogue (<http://cost733.geo.uni-augsburg.de/cost733wiki>). Because of the fact that a comparison between CTCs with different number of classes is difficult, only the circulation catalogues with around 27 classes defined on domain D07 are analysed, including 15 objective and 5 manual CTCs (Tab. 5.8 and 5.9). Daily mean SO₂, NO₂ and PM₁₀ and maximum daily 8 - hour mean CO from Warsaw, Krakow, Upper Silesia, Lodz and Wroclaw are considered for winter (December, January, February) from 1997 to 2002; for Krakow, data was available for 1994 to 2002. Air pollution data and metadata was available from the AIRBASE database (<http://acm.eionet.europa.eu/databases/airbase/>). In addition, SODAR data (winter data, 1994–1999) was also available for Krakow, so that relation between boundary layer conditions and circulation could be examined using different parameters characterizing thermal structure and variability of Urban Boundary Layer. For each day a mean height of convection (C), ground-based inversion (GI) and elevated inversion (EI) were calculated, and the number of hours when each of these boundary layer phenomena were observed determined.

Previously, the relationship between the atmospheric circulation and the surface environment was determined mainly on the basis of the Pearson correlation coefficient, main

square error, and root main square error (YARNAL, 1993; COMRIE, 1992). In this study the Explained Variation (EV) and Within-type Standard Deviation (WSD) (KALKSTEIN et al., 1987) is used. For the relation between CTCs and smog days, the Gini coefficient method (GINI, 1921) is used. The EV and the WSD methods are used for winter air pollution data (1999–2002) from Upper Silesia (v1.1 circulation type classifications (CTCs) catalogue). The relationship between the number of classes and evaluation of different CTCs is observed for both methods. Results show that CTCs with higher number of classes perform better. The comparison between expected marginal means of SO₂ calculated for CTCs chosen by EV and WSD methods (ESLPC30, LWT2 and HBGWL) suggest that the EV metric is a better approach for evaluating the classifications according to their separability. The Gini method compares how different CTCs discriminate well days when air pollution thresholds are exceeded for many pollutants and stations, and is based on the Lorenz curve LORENZ (1905). Only two numbers for each class characterize every classification – a number of days meeting our criteria (e.g. smog days) and the total number of days for each class. The Gini coefficient G associated to a classification is based on the probability $p_i = m_i/n_i$ of occurrence days with some characteristic (e.g. high pollution concentration, large precipitation, fog), calculated for each class and finally sorted according to rising p_i . After sorting:

$$G = 1 - \sum_{k=0}^L (x_k - x_{k-1}) \cdot (y_k + y_{k-1}) \quad (5.5)$$

$$\text{for } x_k = \sum_{i=0}^k \frac{n_i}{N} \quad \text{and} \quad y_k = \sum_{i=0}^k \frac{m_i}{M}$$

where n_i is a total number of days for class i (after sorting), m_i is a number of days meeting our criteria for class i , N is a total number of days for all classes, M is a total number of days meeting our criteria for all classes and L is a number of classes.

5.2.2.3 Results

For winter SO₂, PM₁₀ urban data the Hess-Brezowsky Grosswetterlagen HBGWL is the best classification for most cities and pollutants (Tab. 5.8). Classification calculated on the base of Principal Component Analysis PCACAC27 and Polish classification TCN21 as described in NIEDZWIEDZ (1998) also rank high. Good results are also obtained for Litynski classification LITTC (LITYNSKI, 1969), objective version of Lamb-Weather types LWT2 (LAMB, 1960) and for three objectivized versions of the Hess and Brezowsky Grosswetterlagen (GWTC26, OGWL, OGWLSLP) (JAMES, 2007). The Gini coefficients for Krakow suggest HBGWL, PCACAC27, LWT2 and TCN21 as best classifications (Tab. 5.9), similarly as suggested by EV. The boundary layer in Krakow has been continuously monitored since the beginning of the last decade of 20th century using the vertical sounding sodar (WALCZEWSKI, 1997). To determine the power of the relation between SODAR data and CTCs, the values of EV are used (Tab. 5.9). The highest EV values for all classifications are observed for ground-based inversion height and the number of hours of elevated inversion presence. These parameters play a crucial role in air pollution concentration in Krakow (GODŁOWSKA et al., 2008). The best results (EV=0.41 for GI height and EV=0.33 for EI presence) are obtained for PCACAC27 classification. LWT2, and LITTC classifications also rank high. More information can be found in GODŁOWSKA and TOMASZEWSKA (2010).

Table 5.8: EV values for SO₂, PM₁₀, NO₂ and CO measured in different Polish urban areas, calculated for different CTCs. Correlations in 1st and 2nd places for each data series are in bold and red. EV greater than 0.3 are highlighted in grey. Method abbreviations: a SANDRASC27, b SANDRASC27, c PETISCOC27, d PCACAC27, e NNWC27, f CKMEANSC27, g KHC27, h ESLPC27, i LUNDC27, j TPCAC27, k P27C27, l WLKC28, m LWT2, n LITTC, o GWTC26, p HBGWL, q OGWL, r OGWLSLP, s PERRET, t TCN21.

Method	Cluster				Leader				PCA				Threshold				Subjective				Polish			
	Stations	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t			
EV PM ₁₀	Warszawa	0.21	0.16	0.15	0.24	0.14	0.21	0.17	0.18	0.19	0.17	0.17	0.19	0.23	0.21	0.13	0.32	0.23	0.16	0.14	0.18			
	Kraków	0.21	0.21	0.17	0.24	0.19	0.19	0.21	0.17	0.21	0.20	0.20	0.23	0.24	0.24	0.23	0.21	0.19	0.18	0.16	0.29			
	Wrocław	0.27	0.34	0.25	0.44	0.23	0.31	0.27	0.30	0.30	0.34	0.35	0.40	0.41	0.40	0.34	0.38	0.34	0.34	0.29	0.34			
	Gliwice	0.19	0.24	0.18	0.28	0.20	0.21	0.24	0.23	0.21	0.22	0.23	0.20	0.25	0.23	0.19	0.27	0.24	0.22	0.17	0.26			
EV NO ₂	Warszawa	0.20	0.15	0.11	0.17	0.08	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.15	0.18	0.15	0.28	0.17	0.21	0.15	0.11			
	Łódź	0.13	0.14	0.08	0.17	0.14	0.13	0.09	0.14	0.09	0.10	0.12	0.11	0.15	0.17	0.10	0.24	0.15	0.17	0.14	0.13			
	Kraków	0.11	0.19	0.20	0.23	0.13	0.20	0.25	0.15	0.23	0.22	0.23	0.19	0.24	0.24	0.25	0.12	0.15	0.15	0.13	0.33			
	Wrocław	0.12	0.18	0.10	0.19	0.10	0.17	0.11	0.16	0.16	0.13	0.14	0.09	0.19	0.16	0.16	0.13	0.21	0.20	0.15	0.17			
	Gliwice	0.14	0.22	0.15	0.19	0.10	0.22	0.14	0.14	0.22	0.21	0.17	0.17	0.23	0.15	0.13	0.28	0.14	0.15	0.15	0.18			
EV SO ₂	Warszawa	0.22	0.18	0.12	0.21	0.07	0.23	0.14	0.19	0.22	0.18	0.15	0.2	0.18	0.21	0.11	0.35	0.24	0.26	0.15	0.17			
	Łódź	0.15	0.18	0.11	0.16	0.12	0.19	0.16	0.19	0.16	0.12	0.15	0.15	0.16	0.18	0.12	0.31	0.20	0.21	0.13	0.16			
	Kraków	0.22	0.19	0.12	0.21	0.13	0.17	0.15	0.19	0.17	0.18	0.16	0.16	0.17	0.21	0.13	0.25	0.21	0.21	0.15	0.22			
	Wrocław	0.24	0.21	0.17	0.27	0.11	0.22	0.18	0.21	0.22	0.18	0.26	0.19	0.21	0.23	0.27	0.28	0.26	0.22	0.18	0.20			
	Gliwice	0.30	0.27	0.25	0.34	0.18	0.30	0.31	0.28	0.28	0.28	0.29	0.31	0.31	0.31	0.27	0.48	0.32	0.33	0.24	0.33			
EV CO	Warszawa	0.23	0.20	0.14	0.21	0.16	0.19	0.17	0.14	0.14	0.17	0.16	0.19	0.19	0.19	0.18	0.24	0.15	0.14	0.13	0.23			
	Kraków	0.15	0.20	0.20	0.23	0.11	0.21	0.22	0.15	0.22	0.20	0.19	0.22	0.24	0.21	0.21	0.21	0.18	0.15	0.14	0.30			

Table 5.9: Gini coefficients for smog days occurrence in Kraków and EV of some boundary layer thermal structure characteristics calculated for different CTCs. EV greater than 0.3 are highlighted in grey and Gini coefficients greater than 0.5 are highlighted in yellow. Correlations in 1st and 2nd places for each data series are in bold and red. The bottom three rows include EV and Gini rankings for the methods where particularly high rankings are highlighted in orange. Abbreviations as in Tab. 5.8.

Method	Stations	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t
GINI coef.	Kraków	0.47	0.46	0.43	0.52	0.42	0.49	0.48	0.44	0.46	0.49	0.41	0.48	0.52	0.47	0.42	0.51	0.47	0.47	0.37	0.51
Smog Days																					
EV	Convection	0.12	0.11	0.10	0.13	0.11	0.16	0.05	0.11	0.14	0.12	0.12	0.08	0.14	0.12	0.12	0.16	0.12	0.09	0.15	0.12
Mean	Ground Inv.	0.24	0.37	0.24	0.41	0.19	0.36	0.21	0.27	0.31	0.26	0.34	0.22	0.33	0.34	0.31	0.29	0.25	0.28	0.23	0.35
Height of:	Elev.Inversion	0.12	0.16	0.14	0.18	0.09	0.17	0.12	0.13	0.13	0.09	0.14	0.11	0.15	0.15	0.10	0.16	0.13	0.11	0.09	0.14
EV	Convection	0.09	0.11	0.08	0.12	0.08	0.17	0.07	0.08	0.06	0.07	0.12	0.11	0.11	0.14	0.10	0.17	0.16	0.18	0.17	0.12
Persistence:	EV Ground Inv.	0.09	0.10	0.12	0.16	0.07	0.18	0.08	0.14	0.11	0.11	0.12	0.13	0.10	0.09	0.11	0.14	0.11	0.13	0.11	0.11
	Elev.Inversion	0.26	0.30	0.19	0.33	0.27	0.31	0.23	0.26	0.26	0.27	0.28	0.22	0.31	0.31	0.29	0.18	0.24	0.22	0.18	0.30
Air Pollution	EV Rank	1(1)	1(0)	0(0)	2(7)	0(0)	2(0)	1(0)	1(0)	1(0)	1(0)	1(0)	2(0)	2(4)	2(2)	1(2)	5(11)	2(1)	2(5)	0(0)	4(5)
Smog Days	Gini Rank	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1
Vertical Disp.	EV Rank	0(0)	2(1)	0(0)	2(4)	0(0)	2(5)	0(0)	0(0)	1(0)	0(0)	1(0)	0(0)	2(1)	2(1)	1(0)	0(2)	0(0)	0(1)	0(1)	2(0)

5.2.2.4 Summary and conclusions

Results of this study suggest that winter air pollution as characterised by SO₂ and PM₁₀ and the vertical dispersion conditions are connected to circulation. The NO₂ and CO concentrations, which are mainly generated by the transportation sector, are not so well discriminated by CTCs. The manual classifications seemed to perform best, with the objective PCACA also showing good results, listed as follow: Hess-Brezowsky Grosswetterlagen classification (HBGWL), PCACA, Polish Niedzwiedz TCN21, modified Litynski LITTe, modified Lamb LWT2, and three modified HBGWL (GWTC26, OGWL, OG-WLSLP) classifications. Results obtained using the Gini coefficients for the smog days discrimination are consistent with those obtained from EV.

5.2.2.5 Recommendations

- **Family of algorithms**

Threshold and cluster algorithms and subjective methods better represent these patterns closely related to high thresholds of SO₂, PM₁₀ in Polish urban cities in winter, and similar results are obtained for episodes of smog days. Only threshold and cluster algorithm discriminate well dispersion conditions connected with ground inversion height and persistence of low-laying elevated inversion.

- **Number of classes**

For different examined evaluation methods such as EV, WSD and GINI we observe better results for CTCs with higher number of classes.

5.2.3 Relations between circulation and summer ozone concentration in different European locations

Authors: Anna Monika Tomaszewska and Jolanta Godlowska

5.2.3.1 Introduction

Surface ozone is produced by photochemical reactions triggered by short-wave radiation from the sun, and thus connection between ozone concentration and meteorology can be observed. Meteorology is also responsible for many other processes related to ozone build-up and destruction, such as the chemical reaction rate, the transport of ozone and its precursors (CREILSON et al., 2003; TARASOVA and KARPETCHKO, 2003; HANNA and CHANG, 1994; BERKOWITZ et al., 1996), large-scale downward movements due to atmospheric subsidence (MCKENDRY and LUNDGREN, 2000) and stratosphere-troposphere exchange in the frontline (ANCELLET et al., 1991). In recent decades statistical forecasts of ozone concentration were mostly based on meteorological parameters related to the local scale (THOMPSON et al., 1999), but better forecasts could be made by considering regional information, connected with short and long-distance transport. Analysis of circulation type classifications could help understand and quantify the meteorological conditions that have a significant impact on ozone concentrations on a regional scale. Surface ozone concentrations vary significantly daily but also within the year: in highly populated and polluted Northern hemisphere, smog episodes are generally observed in summer (CHALOULAKOU et al., 1999; CHENEVEZ and JENSEN, 2001; WAKAMATSU et al.,

1990), thus the role of circulation type classifications is evaluated for only June, July and August (JJA) using classifications generated within COST733. The focus is given on (i) ranking of the selected circulation classifications according to their “skill” to stratify ozone data, (ii) ranking of the domains for places where Circulation Type Classifications (CTCs) prepared for different domains can be used and (iii) assessment of the role type of area in CTCs ranking, with special consideration to the location of monitoring stations (rural, suburban and urban areas).

5.2.3.2 Data and Methods

The analysis is based on COST733CAT v1.2 circulation type classifications catalogue (<http://cost733.geo.uni-augsburg.de/cost733wiki>). Only the catalogues with round 27 classes were considered, including 15 objective and 4 manual catalogues (Tab. 5.10) defined on the European domain (D00) and on sub-domains.

Ozone concentration data correspond to maximum daily 8-hour mean of ozone (O_3) EMEP Database¹⁾ from five Polish (years 1997–2002), three Czech (1993–2002), three German (1996–2002), four Austrian (1991–2002), two Hungarian (1999–2002), three Slovenian (1997–2002), five French (1999–2002), four Italian (1999–2002) and four Belgian (1997–2002) stations, each country with at least one urban station and one nearest suburban and one rural station (except two for France).

The explained variation metric (EV) was used to evaluate how well different circulation type classifications (CTCs) discriminate days with different level of ozone concentration.

5.2.3.3 Results

The EV metric is a good parameter for assessing quality of discriminating ozone concentration by CTCs with about 27 classes. Significant differences in the ability to stratify ozone concentration by CTCs for rural, urban and suburban areas were found. Hence it is recommended to analyse data from stations localised in the same type of area. The best partitioning of ozone data was observed for stations localised in rural areas.

The majority of CTCs calculated for D00 domain stratifies ozone data worse than CTCs calculated for every alternative sub-domain (Tab. 5.10). In general, there is a link between CTCs and ozone concentration, but EV values are lower than 0.4 for the majority of CTCs and areas, except for Milan with non-scalable PERRET or scalable PETISCO, and for Grenoble for PERRET classification. For the majority of sites in central Europe, nontransferable and non-scalable for different regions HBGWL, OGWL and PERRET classifications are the best for stratifying ozone data, and results are the worse for Hungary, Slovenia, Austria and the south of Poland. EV values for non-scalable OGWLSLP (based on MSLP only) are not as good as those for OGWL, which is based on mean sea level pressure (MSLP) and 500 hPa geopotential height (GPH). This suggests that to discriminate ozone concentration, that circulation patterns defined from atmospheric variables of high atmosphere should be considered in addition to MSLP. Among objective, scalable CTCs, threshold based classifications seem to perform best, especially LITTC and WLKc27, in particular for D06, D07 and D10. The leader algorithm method PETISCO also performs well for all analyzed sub-domains except D04, where SANDRASc27 is the best scalable CTC (Tab. 5.10).

¹⁾<http://acm.eionet.europa.eu/databases/airbase/>

Table 5.10: Comparison of EV values for $8O_3$ in different European rural areas calculated for different CTCs. Correlations in 1st and 2nd place for each data series are printed in bold red. EV greater than 0.3 are marked in grey. DD: Domain; Coding for models: a CKMEANSC27, b ESLPC27, c GWTC26, d KHC27, e LITTC, f LUNDC27, g LWT2, h NNWC27, i P27C27, j PCACAC27, k PETISCO27, l SANDRAC27, m SANDRASC27, n TPCAC27, o WLKC28, p HBGWL, q OGWL, r OGWLSLP, s PERRET.

City	DD	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
Tatabanya	6	0.11	0.15	0.15	0.12	0.21	0.15	0.18	0.11	0.17	0.18	0.22	0.12	0.22	0.14	0.31	0.24	0.20	0.18	0.20
	7	0.16	0.15	0.19	0.16	0.19	0.17	0.15	0.19	0.22	0.27	0.25	0.16	0.22	0.16	0.26	0.24	0.20	0.18	0.20
	10	0.19	0.16	0.15	0.16	0.25	0.16	0.16	0.17	0.24	0.12	0.21	0.20	0.20	0.23	0.23	0.24	0.20	0.18	0.20
Ljubljana	6	0.12	0.13	0.19	0.15	0.18	0.20	0.22	0.11	0.19	0.17	0.23	0.10	0.18	0.15	0.26	0.17	0.21	0.17	0.16
Slovenia	7	0.14	0.11	0.24	0.19	0.23	0.18	0.19	0.10	0.22	0.20	0.23	0.19	0.26	0.16	0.20	0.17	0.21	0.17	0.16
	10	0.13	0.11	0.21	0.21	0.19	0.22	0.25	0.16	0.27	0.10	0.23	0.16	0.16	0.20	0.21	0.17	0.21	0.17	0.16
Milan	6	0.21	0.24	0.17	0.20	0.23	0.19	0.10	0.15	0.15	0.19	0.24	0.25	0.22	0.27	0.29	0.34	0.30	0.20	0.41
Italy	7	0.16	0.15	0.14	0.17	0.18	0.15	0.18	0.15	0.06	0.15	0.17	0.14	0.18	0.15	0.21	0.34	0.30	0.20	0.41
	10	0.17	0.19	0.22	0.13	0.18	0.16	0.22	0.04	0.22	0.17	0.40	0.18	0.24	0.19	0.33	0.34	0.30	0.20	0.41
Lyon	6	0.20	0.20	0.32	0.30	0.36	0.38	0.17	0.21	0.31	0.27	0.35	0.23	0.17	0.31	0.33	0.31	0.38	0.33	0.35
France	7	0.22	0.21	0.24	0.20	0.22	0.21	0.30	0.15	0.14	0.17	0.31	0.20	0.22	0.21	0.24	0.31	0.38	0.33	0.35
	9	0.15	0.18	0.19	0.11	0.24	0.18	0.19	0.16	0.21	0.16	0.27	0.16	0.13	0.24	0.21	0.31	0.38	0.33	0.35
Grenoble	6	0.30	0.28	0.24	0.23	0.33	0.26	0.12	0.23	0.21	0.29	0.27	0.31	0.27	0.35	0.30	0.31	0.32	0.27	0.40
France	7	0.25	0.21	0.17	0.14	0.21	0.15	0.20	0.19	0.10	0.20	0.24	0.21	0.24	0.21	0.22	0.31	0.32	0.27	0.40
	9	0.16	0.16	0.14	0.13	0.23	0.16	0.20	0.24	0.25	0.17	0.32	0.14	0.19	0.25	0.19	0.31	0.32	0.27	0.40
Brussels	4	0.15	0.15	0.23	0.26	0.21	0.27	0.20	0.29	0.23	0.22	0.23	0.17	0.31	0.21	0.27	0.32	0.32	0.31	0.33
Belgium	7	0.26	0.30	0.30	0.23	0.31	0.27	0.34	0.16	0.18	0.24	0.30	0.28	0.33	0.20	0.20	0.32	0.32	0.31	0.33
	6	0.27	0.27	0.21	0.18	0.36	0.23	0.14	0.31	0.24	0.29	0.24	0.27	0.28	0.28	0.23	0.34	0.30	0.28	0.34
Frankf. a.M.	7	0.25	0.27	0.18	0.14	0.31	0.15	0.23	0.22	0.11	0.27	0.15	0.28	0.27	0.15	0.19	0.34	0.30	0.28	0.34
	6	0.13	0.14	0.09	0.11	0.19	0.16	0.10	0.15	0.15	0.17	0.12	0.15	0.15	0.14	0.14	0.28	0.23	0.16	0.21
Prague	7	0.15	0.15	0.10	0.10	0.17	0.11	0.12	0.17	0.13	0.17	0.15	0.15	0.20	0.11	0.21	0.28	0.23	0.16	0.21
Czech Rep.	6	0.15	0.16	0.17	0.19	0.27	0.17	0.19	0.16	0.24	0.23	0.19	0.17	0.18	0.18	0.25	0.20	0.23	0.19	0.22
Vienna	7	0.20	0.17	0.24	0.23	0.29	0.27	0.23	0.18	0.28	0.28	0.26	0.24	0.21	0.20	0.29	0.20	0.23	0.19	0.22
	10	0.21	0.14	0.22	0.24	0.21	0.23	0.21	0.13	0.33	0.18	0.29	0.22	0.16	0.27	0.17	0.20	0.23	0.19	0.22
GOP Poland	7	0.23	0.17	0.24	0.22	0.22	0.24	0.21	0.15	0.21	0.24	0.20	0.23	0.20	0.20	0.28	0.21	0.20	0.17	0.17

5.2.3.4 Summary and Conclusions

In this study ozone data from the central part of Europe is considered. Results show that non-scalable classifications such as HBGWL, OGWL, OGWL-SLP (centered on Germany) and PERRET (centered on Alpine region) give very good results for partitioning ozone data for most analysed stations. In some cases, objective, scalable classifications over-perform non-scalable methods. The EV values obtained for OGWL-SLP are much lower than for OGWL, suggesting geopotential height data should be considered in the definition of the classification in addition to MSLP. The EV values obtained for HBGWL and OGWL (JAMES, 2007) are similar. For Prague, GOP, Frankfurt, Milan and Tatabanya HBGWL ranks higher than OGWL, but it is the inverse for Lyon, Grenoble, Ljubljana and Vienna. Amongst objective, scalable CTCs, threshold based classifications seem to be the best, especially LITTC and WLKc27, in particular when defined for sub-domains D06, D07 and D10 sub-domains. The PETISCO method ranks highest for all analysed sub-domains apart from D04.

Table 5.11: Rank of the CTCs methods/algorithms.

<i>Methods/ Algorithms</i>	<i>CTCs</i>	<i>EV plays</i>		<i>Next EV > 0.3</i>			<i>Sum</i>
		<i>1st</i>	<i>2nd</i>	<i>D06</i>	<i>D07</i>	<i>D10</i>	
Subjective	HBGWL	1	2	3	1	1	8
	OGWL		2	3	1		6
	PERRET	3	1	1			5
	OGWLSLP			1	1		2
Threshold	LITTC	2	1	2	1		6
	WLKC28	2	1	2			5
	LWT2	1	1				2
	GWTC26			1			1
Cluster	PETISCOC27		2	1			3
	SANDRASC27	1	1	1			3
	PCACAC27	1					1
	NNWC27			1			1
	CKMEANSC27			1			1
PCA	P27C27	1		1			2

5.2.3.5 Recommendations

- **Family of algorithms**

The best methods are subjective HBGWL, OGWL and PERRET, and the threshold LITTC and WLKC28. Good results are obtained for the PETISCOC27 and SANDRASC27 CTCs (Tab: 5.11). The best CTCs for each station for a chosen domain are show in Tab. 5.12.

- **Domain size and locations**

The majority of CTCs calculated for D00 domain stratify ozone data less well compared to the smaller domains, this for the majority of analysed stations, except for Prague – ESLPC27, TPCAC27; Vienna – ESLPC27; Brussels – TPCAC27; GOP – ESLPC27. Highest EV values are obtained for D06 for Lyon (D06 – 11 CTCs with the highest EV value, D07 – 4 CTCs with the highest EV value), Grenoble (D06–11, D07–1, D09–3), Frankfurt a. M. (D06–13, D07–2) and Milan (D06–8, D10–6, D07–1). For Brussels (D07–10, D04–4, D00–1), Vienna (D07–9, D10–5), Prague (D07–8, D06–5, D00–2) and GOP (D07–14, D00–1) the best results are noticed for D07 sub-domain. For Tatabanya (D07–6, D10–6, D06–2) and Ljubljana (D07–7, D10–6, D06–2) the same number of classifications have the best results for D10 and D07 subdomains.

Table 5.12: The best classification (first and second plays) and the next CTCs with $EV > 0.3$ from the chosen domains, for each station separately. DD denotes the domain. EV values of 0.3 or larger are marked in bold and red.

City	DD	Max EV	Rank			Next with $EV > 0.3$								
			1 st	2 nd	1	2	3	4	5	6	7	8	9	
MILAN	6	0.413	PERRET	HBGWL	OGWL	PETISCOC27	PERRET	WLKC28	OGWLSLP	GWTC26	HBGWL	TPCAC27	P27C27	
LYON		0.381	LUNDC27	OGWL	LITTC	OGWL	HBGWL	SANDRAC27	WLKC28	CKMEANSC27				
GRENOBLE		0.401	PERRET	TPCAC27	LITTC	OGWL	HBGWL	OGWL						
FRANKFURT		0.362	LITTC	PERRET	HBGWL	NNWC27	OGWL							
TATABANYA	7	0.269	PCACAC27	WLKC28										
LJUBLJANA		0.255	SANDRASC27	PETISCOC27										
BRUSSELS		0.342	LWT2	SANDRASC27	OGWL	HBGWL	OGWLSLP	LITTC						
PRAGUE		0.276	HBGWL	OGWL										
VIENNA		0.295	WLKC28	LITTC										
GOP		0.277	WLKC28	LUNDC27										
TATABANYA	10	0.253	LITTC	HBGWL										
LJUBLJANA		0.270	P27C27	LWT2										
MILAN		0.413	PERRET	PETISCOC27	HBGWL	WLKC28	OGWL							

5.2.4 Spectral analysis of total suspended particles in connection with circulation patterns in the central and eastern part of Europe

Authors: Sabina Stefan and Florinela Georgescu

5.2.4.1 Introduction

Particulate matters have been identified as one of the most important air pollutants with adverse impacts on human health (SEINFELD and PANDIS, 1998). Local and regional air quality also depends on atmospheric circulation. In particular, the long-range transport of natural or anthropogenic aerosols over distances exceeding national borders is an important process affecting the air quality in urban areas in Europe (MORENO et al., 2005). The long-range transport is strongly connected to the sources of pollutants and to the air circulation. The knowledge of the connection with the air circulation requires reliable methodologies identifying the contribution of weather and circulation types to pollutant levels.

Many methods have been developed to investigate the relationship between air quality data and transport over distances of few hundreds kilometres. Some of them use multiple linear regressions [STADLOBER et al. (2008) and DEMUZERE et al. (2009b)]. Others rely on non-linear multiple regressions or artificial neural networks (PAPANASTASIOUS et al., 2007). In certain cases, back trajectory modelling has been used, in combination with chemical species and/or synoptic weather maps to identify long-range transport sources of polluted air masses that may have an impact on local pollution [VIANA et al. (2003) and VARDOULAKIS and KASSOMENOS (2006)]. The present study establishes a practical methodology for examining the relationship between circulation types and local measurements of Total Suspended Particulates (TSP) for the period between 2001 and 2002. Complementary methods of pollutants typically related to long-range transport of particles, such as the air mass back trajectories method, have also been used for comparison. Finally, this study considers the implication of the domain choice for the sites location.

5.2.4.2 Data and Methodology

Spectral analysis is used to test the links between *in situ* concentrations values of Total Suspended Particulates (TSP) and the circulation patterns described in COST733 Catalogues v.1.2 (input variables for the classification: mean sea level pressure (MSLP), and primarily the algorithms LWT2 (JAMES, 2006), GWT (BECK et al., 2007), PCAXTR (ESTEBAN et al., 2006), SANDRA (PHILIPP, 2007) and TPCAV [HUTH (1993), and HUTH et al. (2008)]. Daily measurements of TSP for an approximately 2-year period (1st January 2001 to 31st August 2002; 608 days) were obtained from the European Topic Center on Air and Climate Change (<http://acm.eionet.europa.eu/databases/airbase/>) for three locations: Aosta (North-Western part of Italy), Vienna (Eastern part of Austria) and Baia Mare (North-Western part of Romania). All sites are placed in the domain 10 from COST733 Classification Catalogues. The spectral analysis was performed by using the Multiresolution Analysis technique (MRA, Wave slim software, WHITCHER and CRAIGMILE, 2004), which is based on Maximal Overlap Discrete Wavelet Transform (MODWT) with Fejer-Korovkin in wavelet filter with 22 points.

In order to identify the circulation types linked to the pollutant concentrations in the chosen locations, the dominant quasi-periodic signals contained in pollutant concentration time series were separated using the MODWT (WHITCHER and CRAIGMILE, 2004), for details see Appendix A in STEFAN et al. (2010). The main circulation types associated to the positive (meaning winter) and negative (meaning summer) phases of these signals are identified. The circulations types with highest frequency of appearances are linked to pollutants concentrations values corresponding to the positive phase of the quasi-periodic signal. For a value of 0.75 from the TSP annual cycle standard deviation, we have determined the main circulation type over the available time interval by counting the number of appearances for each type both for positive and negative parts of the annual cycle. As we are interested mainly in long range transport of pollutants, we have only shown the results for the positive parts of the quasi-periodic signal. The HYSPLIT 4 model from NOAA Air resources Laboratory (ARL) was also used to compare the circulations to the air mass back trajectories (DRAXLER and ROLPH, 2003). More information can be found in STEFAN et al. (2010).

5.2.4.3 Results

The spectral analysis was applied for the period between 2001 and 2004 to obtain the confidence statistic results, but the links between the long-range transport of pollutants and the circulation types were only considered for the 2-year period of common data (2001–2002). The full spectral analysis shows a dominant one-year periodicity for all the time series (STEFAN et al., 2010), explaining around 22% of variance for each time series. All other periodicities have less than 5% contribution to the variance. As we were interested in the long-range transport of pollutants, we have only accounted for the positive phase resulting from the spectral analysis, when the concentrations are maximal. This is because the concentrations exceeding the average value are explained by the intrusions of pollutant from long distance.

Fig. 5.33 shows the relative frequency of each type of circulation, over the period 2001–2002, for positive spectral analysis, when the influence of the remote air pollution sources is the strongest, in the case where the sources of pollution are distant. The dominant circulations frequency associated to the long-range transport of pollutants is greater for TPCAV classification than in all the others, and smallest for LWTs. In TPCAV classification the number of circulation types is the smallest (9) and the LWT2 classification has the largest number of circulation types (26). To compare the five classifications we have defined the most frequent circulation types, originally identified by numbers, by taking into account the LWT2 classification definitions. We have made this choice because the ERA40 composite maps do show a good relationship between LWT2 types definitions and known synoptic types definitions in various regions (not shown here). The consistency in circulation types of SANDRA and LWT2 defined on D10 classifications is illustrated in Fig. 5.33, where the frequency of circulation types associated with pollution episode is similar for both classifications for the three study sites. Note also that SANDRA and LWT2 CTS have similar composite MSLP patterns, with the dominant circulation described as USE (Unbiased South-Easterly) type (not shown). The air mass back-trajectories (DRAXLER and HESS, 1998; DRAXLER and ROLPH, 2003) and synoptic maps associated with pollution events of January 2001 (Figs. 4 in STEFAN et al., 2010) confirm that intense pollution episodes observed for the three sites occur during USE circulation episodes, suggesting that long-distance pollution on

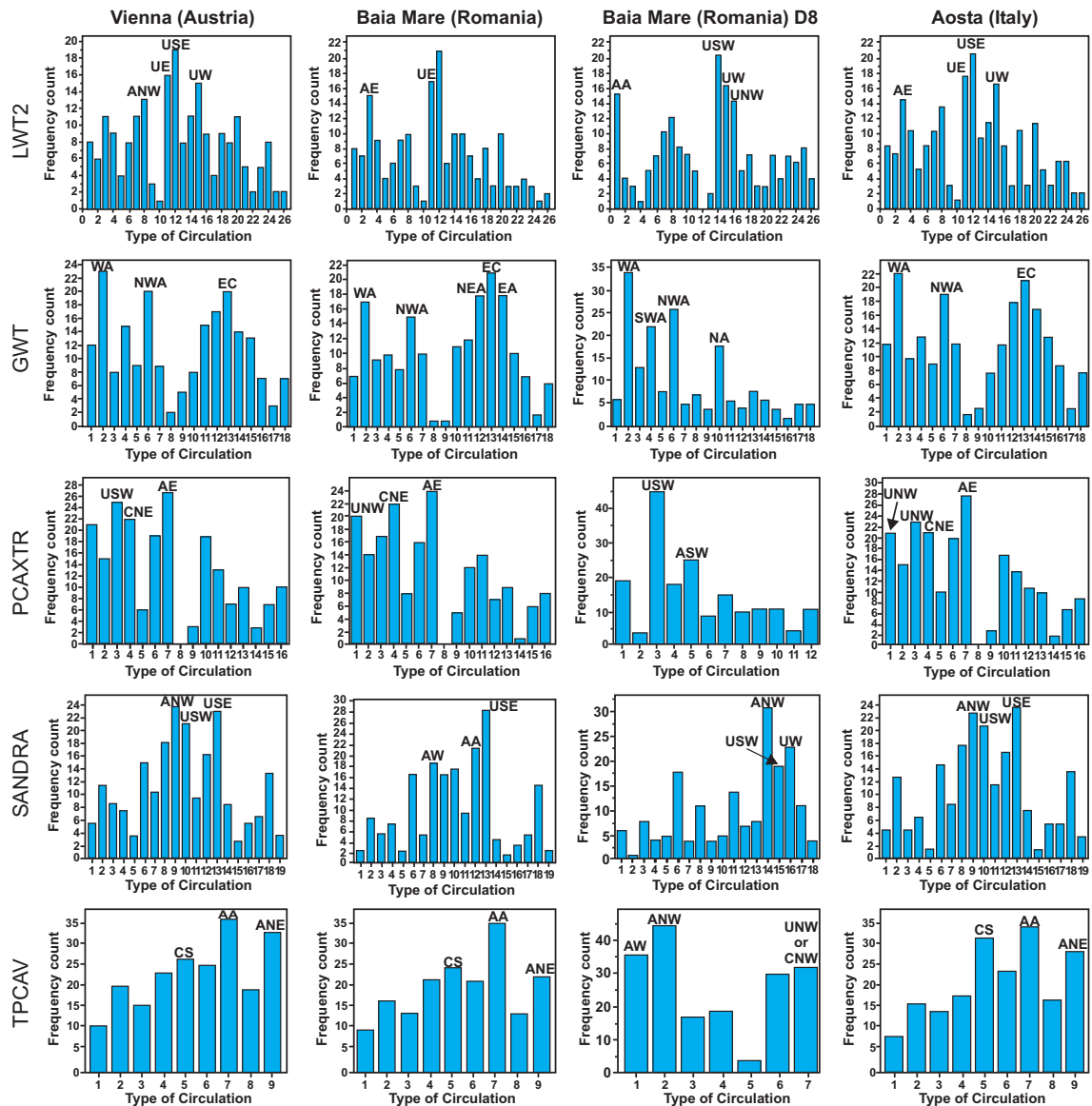


Figure 5.33: Circulation types frequency counted for the positive part (winter) of the annual component at Vienna (AU), Baia Mare (RO) and Aosta (IT).

those sites is mostly triggered by such atmospheric conditions. In case of Baia Mare site, located at the border of D08 and D10 (and not in the centre of D10), the circulation types frequency for classifications defined with the same algorithms but on two different domains are different (Fig. 5.33, the second and third columns). This might be due to the location of the study site at the edge of the both domains.

5.2.4.4 Summary and Concluding Remarks

The daily concentration values of Total Suspended Particles (TSP) from years 2001 and 2002, for three sites, Baia Mare (RO), Vienna (AU), Aosta (IT), have been analyzed to search for relationships between atmospheric circulation (as represented by circulation types) and long-range transport of pollutants. To determine this connection the following

procedures have been used: (i) the spectral analysis of the TSP concentration; (ii) Circulation Types Classifications and associated Circulation Types from the COST733 catalogues; (iii) the back trajectory model (HYSPLIT4) applied to several winter TSP intense pollution episodes.

The method connecting the long-range transport of TSP with weather and circulation types proved successful. Maxima TSP concentration episodes seem to be associated with dominant easterly air circulation for the Eastern European sites, and with south-west air circulation for the Central European sites. This is because easterly to north-easterly air circulations episodes occur more frequently due to the high pressure zone activity in the northern part of Europe.

The study sites being located in the southern part of the anticyclone, intense pollution episodes are generated by long-range transport of pollutants. In addition, the study emphasizes that the choice of the domain for the analysis of the circulation types is very important (see case of Baia Mare). Therefore, for a correct analysis of relationship between the circulations catalogues and long-range transport of pollutants it is necessary to select the domain by taking into account the following: (1) the positions of the sites for the analysis (generally to be in centre of the domain) and (2) the orography of the specific area which can influence the synoptic patterns.

5.2.4.5 Recommendations

- **Family of algorithms**

The COST733 circulations Catalogues v1.2, have to be selected according to the algorithm used. It emerged that optimization and PCA-based algorithms detect patterns reflecting the long-range transport.

- **Domain size and locations**

The choice of the domain for which the CTCs are defined is important, and should be chosen so that the positions of the study sites are near the centre of the domain. Note that the orography of the specific area could also influence the synoptic patterns.

5.2.5 The explanatory power of circulation patterns on surface ozone concentrations in Central Europe

Authors: Matthias Demuzere, Pavlos Kassomenos and Andreas Philipp

5.2.5.1 Introduction

Investigating the link between the large-scale circulation and an environmental variable can in general be addressed in two fundamentally different approaches, as was first suggested by YARNAL (1993) and later on adopted by CANNON et al. (2002). The circulation-to-environment approach classifies the circulation data (e.g. sea level pressure) and then seeks relations with the local-scale environmental variable (e.g. ozone). On the other hand, the environmental-to-circulation approach structures the circulation data based on indices structuring the environmental variable, so that composite maps of the circulation variable can be derived for a specific environmental condition. Whilst the former is often used as a downscaling tool also for present-day and future climates (e.g. DEMUZERE and VAN LIPZIG, 2010), the latter structures the circulation data based on one or more criteria defined by the environmental variable and cannot be used in a predictive manner. Nevertheless, the environment-to-circulation approach can provide some physical evidence in the driving large-scale variable conditions that form the basis of this specific environmental (in this case ozone) event. Therefore, this research paper will employ both approaches (results are only shown for the circulation-to-environment approach) to explain the explanatory power of circulation patterns with respect to ozone concentrations in Central Europe (DEMUZERE et al., 2010).

It is clear that an objective evaluation of the explanatory power of CTs on the region they are derived for is crucial for choosing an appropriate circulation classification methodology. Distance measures are frequently used tool to quantify the between-type variance against the total variance (see e.g. section 6 in HUTH et al., 2008). Here we follow the suggestion by SCHIEMANN and FREI (2010) using the Brier skill score, a skill score often used for the evaluation of probabilistic or ensemble forecasts. This method is applied to quantify the ability of the circulation type classification schemes to describe the day-to-day variations in ozone, and more specifically the ability of these classifications to represent the observed probabilities of exceeding the $120 \mu\text{g}/\text{m}^3$ threshold for the 8-hourly mean maximum O_3 concentrations (m8hO_3) set by the European guidelines on Air quality (EU, 2008).

5.2.5.2 Data and methods

Daily m8hO_3 concentrations are selected from the AIRBASE network (<http://acm.eionet.europa.eu/databases/airbase/>) for 130 rural background stations in Germany, Switzerland, Austria and the Czech Republic all located in the main domain of interest (D07). As the extent of the data is on the lower time end constrained by the continuity of the ozone series and on the higher end on the availability of ECMWF ERA40 dat84 a (see later), only the period from 1996 to 2002 is considered. The basic input data for the classification techniques is the ERA40 reanalysis sea level pressure data (SLP) provided by ECMWF. For the baseline COST733CAT evaluation version 2.0, 12 UTC SLP for the whole period 01/09/1957–31/08/2002 on a $1^\circ \times 1^\circ$ grid resolution is selected. From the circulation patterns retained for the whole year,

only the types for the summer months June, July and August (JJA) or selected for the period 01/06/1996–31/08/2002, resulting in 644 days to be analysed. As a selection of methods are also tested on their sensitivity to different input variables, the following variables are also selected from the ERA40 database and used for the experiments addressed in section 4.2 of [DEMUZERE et al. \(2010\)](#): 500 hPa geopotential height (Z5), Thickness between 500 hPa and 850 hPa geopotential height (K5), Vorticity of the 500 hPa GPH level (Y5) and 2 meter temperature (TT). For the domain sensitivity analysis (see section 4.1), SLP data is also selected for 4 additional domains on a $1^\circ \times 1^\circ$ resolution.

The COST733CAT version 2.0 is taken as a reference, selecting all classifications for all number of classes (00, 09, 18 and 27), derived for the whole year without sequencing and based on sea level pressure. Furthermore, we intend to address some sensitivity studies with respect to some of the standardization steps (e.g. taking only SLP as variable to classify), more explicitly with respect to the domain size, the input variables, the seasonality, sequencing and some tests with respect to the preconditioning of the circulation algorithms towards a target variable, here temperature (with different weights).

5.2.5.3 Results

In this study, the classification of circulation patterns software COST733CLASS is tested on its ability to explain surface ozone concentrations in Central Europe. The stations are selected based on the availability of continuous time series and ERA40 data, resulting in a selection of 130 background rural stations spread over Germany, Austria, Switzerland and the Czech Republic. The two main approaches in synoptic climatology are used to elaborate the results: (1) the circulation-to-environment approach using the probabilistic skill score as a quantitative measure for the explanatory power of the CTs and (2) the environment-to-circulation approach, used to get more physical insight in the large-scale synoptic conditions favouring high ozone concentrations. Not only this exercise provides insight in the application of circulation pattern for air quality, but the software can be used for a variety of sensitivity experiments with respect to domain size (Fig. 5.34), input variables, seasonality, sequencing and conditioned circulation patterns. For all experiments, the explanatory power of the classifications is quantified using the normalized resolution component of the Brier skill score as suggested by [SCHIEMANN and FREI \(2010\)](#). This score measure the probability of the m8hO_3 concentration to exceed the $120 \mu\text{g}/\text{m}^3$ O_3 threshold dependent on the prevailing circulation type.

First, the main properties of the baseline CTs using SLP as input variable for the Central European domain D07 with 1-day sequencing are described through the class frequencies of each methodology. Over all number of circulation types, most methods reflect a uniform distribution of the types over the whole year. In contrast, the optimization methods tend to produce CTs that are seasonally varying in their frequency of occurrence. Furthermore, some methods have the tendency to produce one class occurring for more than 50% of the time.

Although the differences in frequencies are substantial for some methods, no clear link is found with the Brier skill score results. The methods do have an increasing BSS with higher number of circulation classes. Furthermore, the scores tend to be similar for each method over all class size groups, with some exceptions such as LIT. In a second step, the functionalities of the COST733CLASS software are fully explored by a set of sensitivity experiments for different domain sizes, input variables, seasonality, sequencing and the

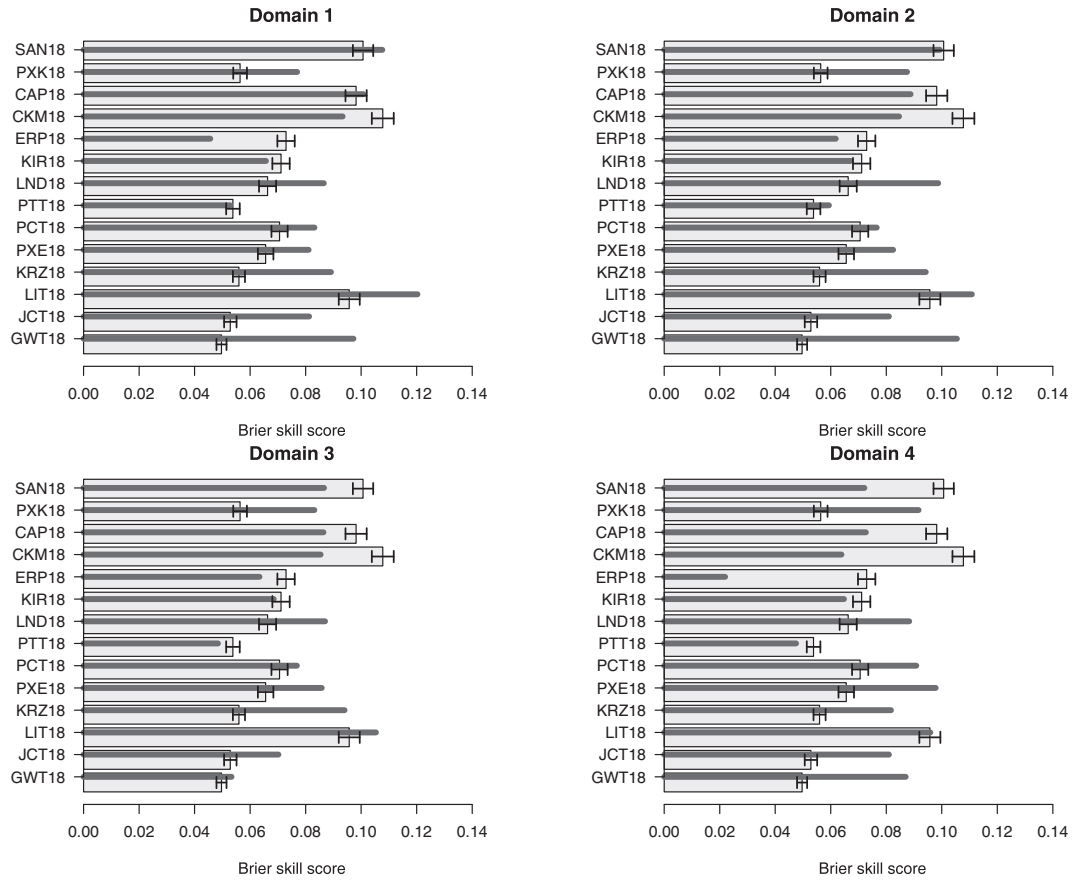


Figure 5.34: The domain size dependent Brier skill score averaged over all stations for all classification algorithms included in the *COST733CLASS* software. The dark grey bars represent the domain size experiment BSS and the light grey bars the baseline BSS for approximately 18 types. The upper left window presents results for domain 1, upper right for domain 2, lower left for domain 3 and lower right for domain 4. More information on the uncertainty range shown by the black error bars can be found in [DEMUZERE et al. \(2010\)](#).

conditioning of the circulation patterns towards a target variable with different weighting factors. For all experiments, no overall conclusions can be drawn. Depending on the number of classes and the methodology, some methods improve their skills with respect to surface ozone properties for the different experiments while others deteriorate. The optimization methods show a variable skill sensitivity with respect to the domain size experiments (Fig. 5.34).

With respect to the classification of upper atmosphere variables, the results overall worsen. For this subset of classifications, this result confirms what was suggested previously by other authors, i.e. the inclusion of additional levels yields only little extra information over using a single level owing to a high degree of dependence among individual levels ([KIDSON, 1997](#); [ROMERO et al., 1999](#)). On the other hand, a gain in score is obtained when the *COST733CLASS* software is only applied for the summer months June, July and August. The BSS for the PCA and leader-based methodologies are positively correlated to an increase in domain size. The same is also true with respect to the application of different input variables. As an illustration, the patterns having the strongest correlation with the SLP composite pattern derived from an environment-to-

circulation approach are shown for PCT. For each of the input sensitivity experiments, the SLP composite shows a tendency towards re-location of its high-pressure centre depending on the experiment, and a strengthening of the pressure values. The composite patterns for vorticity, 500-850 hPa thickness and 500 hPa geopotential height show a tendency towards more persistent upper atmosphere conditions, compared to the more zonal-flow oriented pattern derived from the environmental-to-circulation approach. For all methods, increasing the sequencing length from 1 day to 4 or 10 days provides only a negligible effect. A last sensitivity experiment tested the conditioning of the circulation patterns with respect to 2 meter temperature, often shown to be strongly related to ozone. Here better results are obtained for the optimization methods, while the PCA and leader algorithm based methods have decreased skill scores. Overall, imposing different weighting factors on the temperature field, the latter up to three times more important than the SLP input, does not alter these findings.

5.2.5.4 Conclusions

Apart from the objective to test this selection of circulation pattern methodologies – within the COST733 framework – with respect to their explanatory power on surface ozone concentrations in Central Europe, this work is especially indented to provide insight in the capabilities of the COST733CLASS software. By including the original catalogues developed by their respective authors, and comparing them with the ones reproduced by the software, the analyses demonstrated that the software is able to retain the main properties from the original circulation classification schemes. Moreover, the software has interesting additional features like the possibility to classify multiple variables, in order to derive more complex air mass or pure weather type classifications, extended with a possibility to weight some or all input fields. Furthermore, the COST733CLASS software can be compiled on any possible time step (hourly, daily, monthly...) and an user-defined time frame. Finally, the software is user-friendly and delivered with an extensive user guide and can be compiled under various operating systems.

5.2.5.5 Recommendations

- **Family of algorithms**
With respect to families of algorithms, there are no clear differences.
- **Domain size and locations**
PCA and leader based algorithms tend to improve their results for a larger domain size, while this effect is inverse for the optimization methods.
- **Number of classes**
The methods have an increased performance with a larger number of classes. This of course depends on the Brier Skill Score used here, imposing an intrinsically better separation of ozone events in the classes due to a higher number of these classes.
- **Input variables**
Including additional levels yields only little extra information over using a single level owing to a high degree of dependence among individual levels. Testing the conditioning of the circulation patterns with respect to 2 meter temperature shows better results for the optimization methods, while the PCA and leader algorithm

based methods have decreased skill scores. Overall, imposing different weighting factors on the temperature field, the latter up to ten times more important than the SLP input, does not alter these findings.

- **Seasonal**

A gain in score is obtained when the COST733CAT software is only applied for the summer months June, July and August.

- **Sequencing**

For all methods, increasing the sequencing length from 1 day to 4 or 10 days does provide only a negligible effect.

5.2.6 Conclusions and recommendations – subgroup “Air quality”

The majority of the case studies in the air quality subgroup deal with surface ozone at various locations in Europe. First of all it is shown that long-range transport is important for chemical substances, so that the choice of your domain location is important. Generally, selecting the domain with your location(s) of interest in the center seems to be optimal. Furthermore it is shown that smaller domains seem to be better in capturing the local synoptic conditions that are characterizing peak concentrations of both ozone and TSP. For the latter, the CTs are also able to reflect the relation with e.g. the boundary layer height and its daily persistence. Tab. 5.13 presents an overview of (some of the) general findings of these case studies. No clear recommendations can be made towards the choice of algorithms. Depending on the metric used, the higher the number of classes, the better the result. Other elements do not have a significant impact and therefore do not provide conclusive evidence for recommendation.

Table 5.13: Summary of the results from the case studies in the subgroup “air quality”. The symbols refer to: (1) – -/++: A lower/higher number of classes improve the results; (2) +/-: improvement/deterioration of the results; (3) \approx : no conclusive evidence for a significant impact and (4) blank: This criterion is not tested.

<i>Cat. version</i>	<i>Variable tested</i>	<i>Preferred algorithm (class)</i>	<i>Preferred domain (domain of interest)</i>	<i>Addt'l. nr. of classes</i>	<i>input variable</i>	<i>Seasonal ?</i>	<i>Sequence ?</i>
1.1 & 1.2	O ₃	\approx	D06/D07 (Poland)	++*)			
1.1 & 1.2	SO ₂ , PM ₁₀ , CO, NO ₂	THR,	D07 (Poland)	++			
1.2	O ₃	SUB LDR	smaller		+		
1.2	TSP	OPT PCA					
2.0	O ₃	\approx	\approx	++*)	\approx	+	\approx

5.3 Applications in Extremes

Meteorological extremes and their impacts are amongst some of the most damaging natural hazards, with huge economical impact through lack of income, disruption of economical activities, destruction of infrastructures and even human casualties. The ability to characterise the atmospheric conditions that describe the different phases of climate variability and in particular those conditions which trigger such extreme events is a necessary step towards the prediction, prevention and mitigation of their impacts. Research in meteorology has proved that the physics of the atmosphere can explain climate variability as well as the occurrence of many extreme events, and such empirical and expert knowledge is used operationally through local and regional weather forecasts. The apparition of automatic and semi-automatic (hybrids) algorithms that classify atmospheric patterns could provide an objective mechanism to characterise the triggers of extreme events. Such algorithms could be powerful tools to predict the occurrence of events (medium range to multi-seasonal forecasting) or to assess potential changes in the frequency of such atmospheric patterns, and by extension, in the frequency of extreme events under different climatic change scenarios.

This section presents a range of analyses between atmospheric circulation patterns and meteorological extremes and their impact. The work focused on three main research questions:

- 1 Can automatic or hybrid classification algorithm generate catalogues of atmospheric circulation types with strong links to meteorological extremes? Statistical analyses were used as screening method so that several dozens of different algorithms can be tested (cf. Subsection 5.3.6);
- 2 Can automatic or hybrid classification algorithms generate atmospheric circulation types that reproduce the synoptic atmospheric patterns known to trigger extremes (cf. Subsections 5.3.2 and 5.3.3);
- 3 Can automatic or hybrid classification algorithms generate time series and catalogues of atmospheric circulation types that reproduce the sequencing of precipitation or extreme events triggers (cf. Subsections 5.3.1 and 5.3.4).

Analyses focused on local (e.g., in 5.3.3), national or regional (e.g., in 5.3.1, 5.3.2, 5.3.4 and 5.3.5) to continental (cf. Subsection 5.3.6) scales throughout Europe, and in particular central and Eastern Europe.

The section first presents studies on meteorological extremes and concentrates on cyclones (5.3.1), heavy precipitation (5.3.2) and freezing precipitation (5.3.3). Second, studies of three specific impacts are reported: droughts (5.3.4), floods (5.3.5) and snow avalanches (5.3.6).

5.3.1 Circulation types and associated severe weather in Romania

Authors: Florinela Georgescu and Sabina Stefan

5.3.1.1 Introduction

The study of the circulation types is a topic of permanent interest for European meteorologists and climatologists, with an already existing huge number of papers dedicated to it. Circulation types were often studied in connection with weather types, so as the two notions come to superpose. The indestructible connection between the circulation types and the weather types is very well synthesized in the classical work of Romanian researchers N. Topor and C. Stoica, “Circulation types and atmospheric action centres above Europe” (TOPOR and STOICA, 1965). In order to classify the atmospheric processes in the Romanian area, the notion “main circulation form” was used, “characteristic for the average evolution of the weather above Central and South-Eastern Europe, with peculiar stress on the weather conditions in our country”.

The present study addresses both subjective and objective circulation approaches; the former pays more attention to the physical interpretations, in comparison with the latter that is only carried out through objective methods, thus becoming applicable in the fields of meteorology and synoptic climatology. Noteworthy is that a subjective approach uses the meteorologist’s knowledge and experience. The best known and still used subjective classifications developed for various regions, at various scales are those of Hess and Brezowsky (HESS and BREZOWSKY, 1969) and that of Lamb (LAMB, 1960, 1972). Lamb’s subjective classification was used by Jenkinson and Collison (JENKINSON and COLLISON, 1977) so as to obtain an objective classification scheme that uses daily grid-point mean sea level pressure data. The objective and the original subjective Lamb scheme were compared by JONES et al. (1993).

A correlation between the cyclone frequency into a domain considered to be representative for Romania and the circulation types, in conformity with “COST733 Catalogue of Circulation Types” [<http://cost733.met.no/>] has been established and the physical interpretation of the results has been formulated.

5.3.1.2 Data and Methods

The selected domain ranges within 35°–55°N latitude and 10°–35°E longitude, appropriate to Domain 10 from COST733 Catalogue. A subjective analysis of cyclone frequency has been performed for the cold period (November–March) between 1996–2002 years, using daily NCEP/NCAR reanalysis data for the sea level pressure (KALNAY et al., 1996, <http://www.cdc.noaa.gov/data/reanalysis/reanalysis.shtml>). Daily, all closed nuclei with mean sea level pressure (MSLP) equal to or lower than 1015 hPa were counted for the present statistics. Thus, 389 cyclones were retrieved, the majority of them being of the mesoscale type. The monthly occurrence frequency was computed by dividing the number of cyclones counted in one month of one year by the total cyclones number from the analysed interval.

Afterwards the monthly occurrence frequency of each type of circulation from the LWT2 COST733CAT-1.2 catalogue throughout the interval (total number of occurrences of one certain type divided by total number of days) was computed. The LWT2 method

is a modified and improved version of the objective Jenkinson-Collison (JC) system for classifying daily MSLP fields into 26 flow categories, indicating flow direction and vorticity. More information can be found in [GEORGESCU and STEFAN \(2010\)](#).

5.3.1.3 Results

In the cold period of the year (November–March) the highest cyclone frequencies occur in the period November 1997–December 1998, especially for the November and December months. Also, in the 2000–2002 cold period (winters) the cyclonic activity was reduced in respect with the interval of 1997–1999. The results show the highest frequency for anticyclonic circulation types (i.e. AA–Anticyclonic Centred, AE–Anticyclonic Easterly and ASE–Anticyclonic South-Easterly), followed by the unbiased types 11 and 12 (i.e. UE–Unbiased Easterly and USE–Unbiased South-Easterly). The correlations between the cyclones monthly occurrence frequency and circulation types were made for each month of the year. As expected, the correlation between cyclones frequency and cyclonic and unbiased circulation types was better than for anticyclonic one. Consequently, the circulation types 11 (UE–Unbiased Easterly), 18 (CC–Cyclonic Centred), 20 (CE–Cyclonic Easterly) and 21 (CSE–Cyclonic South-Easterly) were selected to be analysed in detail.

Both the MSLP maps from the LWT2 Catalogue (Fig. 5.35) and the correlation graphs (Fig. 5.36) are shown for circulation type 20 and 21. The graphical correlation shows a time variability due to the mesoscale nature of the cyclones and their short life cycle compared to the persistence of large-scale circulation types. Additionally, for periods with many circulation types it is difficult to establish a connection to the cyclonic activity. Thus for analyzing the connection between cyclonic activity and air circulation types, a simple statistics (a correlation coefficient) is not appropriate.

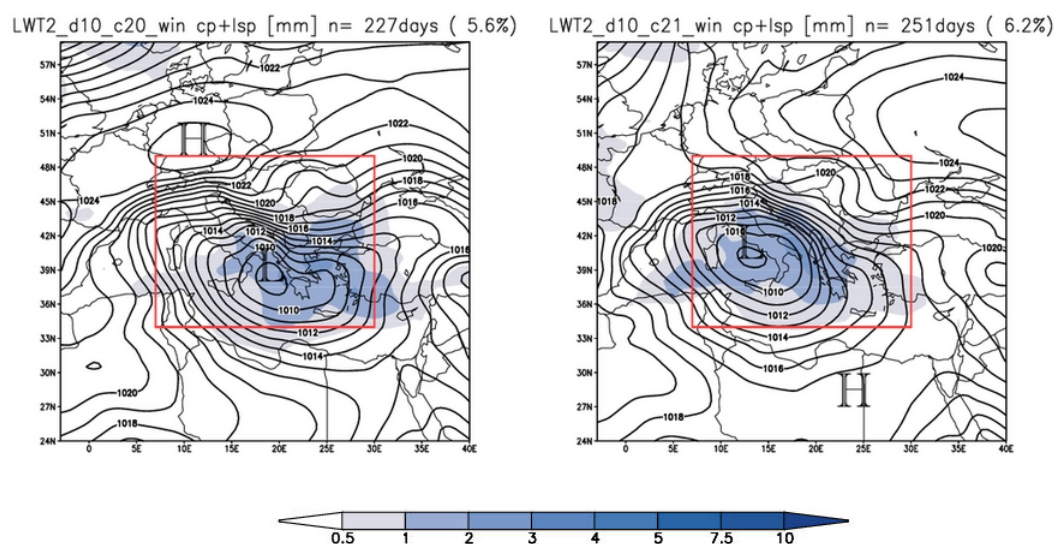


Figure 5.35: Composites of mean sea level pressure (isolines) and precipitation amount (coloured areas, coded according to the colour scale below) of LWT2 type 20 (left) and type 21 (right).

For the chosen domain, this study points out that an intense cyclonic activity is present with circulation types that have a dominant eastern component. This important result

can be related to both the influence of the Black Sea (forcing induced in cold months of the year) and the large frequency of blocking air circulation over Northern Europe. The blocking determines a cyclone occurrence at lower latitudes of the selected domain and generates eastern or southeastern air circulations toward Romania. The eastern component of air circulation types is also present in case of the circulations which have the largest frequency in the cold period of year, AE and ASE.

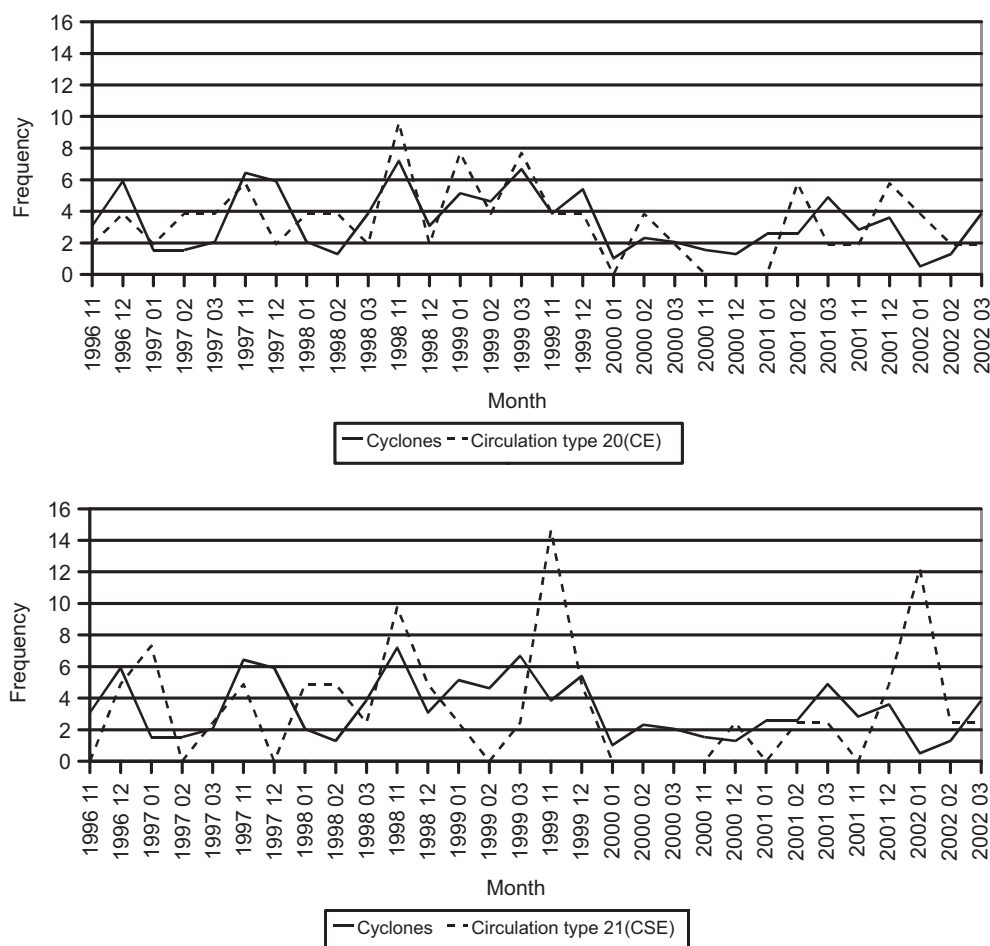


Figure 5.36: Circulation type and cyclone occurrence frequencies versus time.

5.3.1.4 Summary and Conclusions

This work shows the results of combined analysis statistics and physics. The statistics analysis shows the dominant type of air circulation at synoptic scale that determines the larger cyclone frequency of occurrence; the physical analysis explains the frequency of cyclones occurrence in different air circulation types. In the cold period of the 2000–2002 years, the cyclonic activity was reduced comparatively to the first period, 1997–1999. The correlation was variable in time because the cyclones are mesoscale ones and their life cycle is shorter than a circulation type at the large-scale. In addition, in the periods with a great number of circulation types it is difficult to establish a connection to cyclonic activity. The anticyclonic circulation types seem to be the more frequent in this selected period over the chosen domain.

The correlation between cyclones frequency and cyclonic and unbiased circulation types was better than for anticyclonic types. The connection between the cyclones occurrence and circulation type frequencies shows that the cyclonic activity in the domain is important especially during the periods with eastern or south-eastern dominant air circulation. The Black Sea influences the occurrence of intense cyclonic activity for the east or south-east air type circulation.

5.3.1.5 Recommendations

No recommendations can be given here, as this study addresses only the link between LWT2 types and cyclone activity.

5.3.2 Circulation types and associated precipitations over Bulgaria

Authors: Neyko Neykov, Lyubov Trifonova, Ilian Gospodinov and Plamen Neytchev

5.3.2.1 Introduction

The distribution of precipitation across the territory of Bulgaria and their seasonality are mainly determined by synoptic-scale circulation conditions and the land-sea contrast by season, and the large-scale features of the country's relief. The later factor consists of the following major features: The zonal extension of the Stara Planina through the center of the country and the Rila-Rhodope mountainous massif to the south present a natural barrier to the invasion of cold air masses with polar origin towards the southern part of the country. These mountains are also a barrier to warm air masses which have to overflow them in order to reach northward. Actually the country is divided in half into North and South Bulgaria by the Stara Planina mountain chain. This plays a major role in the formation of the precipitation and the temperature regime of either side. A significant difference in the precipitation regime is also observed between the western and the eastern parts of the country. For example heavy precipitation occur in: (i) North Bulgaria almost exclusively in the warm half of year; (ii) NW and NC Bulgaria in the early warm season; (iii) NE Bulgaria in the late warm season; (iv) South Bulgaria mostly in the warm season and the early cold season; (v) SE and SW Bulgaria in late warm season; (vi) SC Bulgaria in the early cold season. More details can be found in [BOCHEVA et al. \(2009\)](#), [BOCHEVA et al. \(2010\)](#) and [GOSPODINOV and DIMITROV \(2010\)](#).

The objective of this study is to assess the quality of the COST733CAT v.2.0 circulation type classifications. We look at the synoptic-scale circulation types that concern Bulgaria and are associated with measured daily precipitation totals greater than 60 mm registered at least in 5 stations.

5.3.2.2 Data and Methods

Daily precipitation totals from 118 Bulgarian stations (29 synoptic, 52 climatological and 37 rain gauges) with altitude below 1000 m for the period 01.01.1960-30.09.2002 are used. The time of measurement is 7.00 a.m. (local time). Only cases with daily precipitation amount greater than 60 mm (heavy precipitation) registered at least in 5 stations are considered. There are 30 such cases. The historical archive of synoptic maps of the National Institute of Meteorology and Hydrology (NIMH) and the NCEP/NCAR Reanalysis data and maps are used. The maps given below that illustrate the weather patterns are courtesy of <http://www.wetterzentrale.de/topkarten/fsreaeur.html> and are based either on the NCEP/NCAR Reanalysis or the operational analysis of the their GFS forecasting system. We also look at the COST733CAT v.2.0 (<http://cost733.geo.uni-augsburg.de/cost733wiki>) circulation type classifications concerning our 30 cases. The following catalogues WetterLagenKlassifikation (WLK), GrossWetterTypes (GWT) and Kruizinga (KRZ) with different input variables (Tab. 5.14) defined on the European domain D10 are chosen for this evaluation.

5.3.2.3 Atmospheric dynamics of heavy precipitation events in Bulgaria

A typical weather pattern that provides conditions for heavy precipitation in the cold season in Bulgaria is the classic Mediterranean cyclone passing near the country by different trajectories. An example is given in Fig. 5.37.

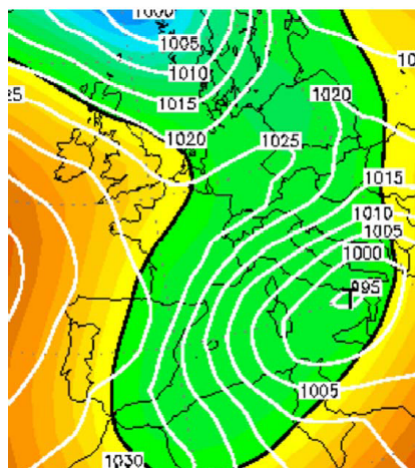


Figure 5.37: Height (dm) of geopotential surface 500 hPa in color and mean sea-level pressure (hPa, white contour), 2 December 1969.

Fig. 5.38 shows another typical weather pattern that provides conditions for heavy precipitation in SW and SC Bulgaria in the cold season and mostly in its early half. It is the weather pattern of a deep trough to the northwest of Bulgaria or a stationary low cut over Italy. When such synoptic-scale structure is positioned to the west of the country, Bulgaria is under the southern or southwestern mid-troposphere jet in the forehead of the low.

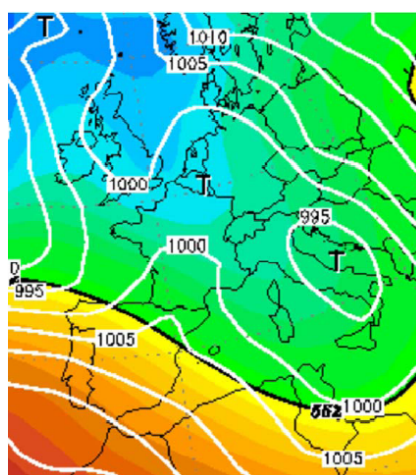


Figure 5.38: Height (dm) of geopotential surface 500 hPa in color and mean sea-level pressure (hPa, white contour), 23 December 1981.

Heavy precipitation in late summer and early autumn can be observed in East Bulgaria when cyclonic systems with Mediterranean origin move into the Balkans and block over. They are usually suppressed by a well developed anticyclone over Eastern Europe. This

provides conditions for convergence of wind near the surface which favours convection. It is combined with strong mid troposphere flow from southeast in the general circulation of the cyclonic system. On the other side, in late summer and early autumn, the sea water is relatively warm compared to the land surface and the thermal force is available over sea rather than over land. The air over sea is by default humid and thus moisture is also available in the air that undergoes convection (see Fig. 5.39).

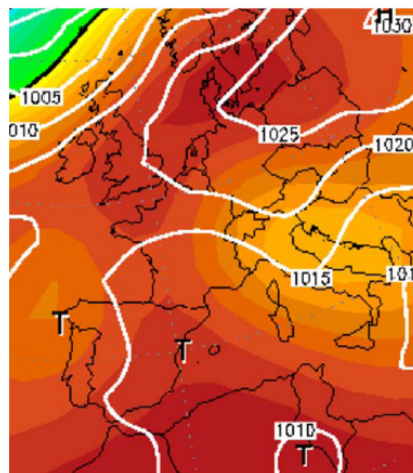


Figure 5.39: Height (dm) of geopotential surface 500 hPa in color and mean sea-level pressure (hPa, white contour), 3 September 1999.

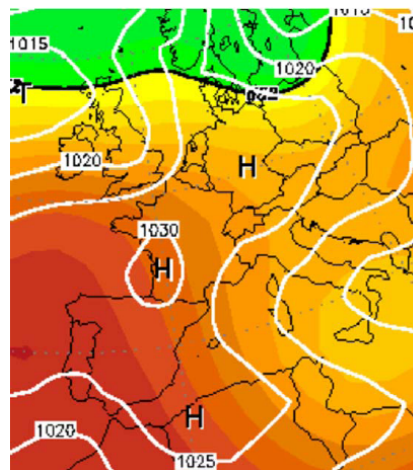


Figure 5.40: Height (dm) of geopotential surface 500 hPa in color and mean sea-level pressure (hPa, white contour), 6 September 1969.

During the warm season a typical synoptic situation that provides conditions for heavy precipitation is cyclonic structure, developing to the west of the Balkans near the Alps that are, however, not cut from the Polar front. An example is given in Fig. 5.40. The cold front associated with such cyclonic system usually stretches over the West Balkans from southwest to northeast and can be stationary. This provides convergence of wind near the surface that favours convection. Additionally, the West and Central Balkans are mountainous and this provides orographic trigger for convection.

This feature predetermines the fact that the Central Balkans and West Bulgaria are the most endangered area for convective precipitation within this pattern.

Another typical case for the entire warm season and countrywide, but mostly for SW Bulgaria is given in Fig. 5.41. When relatively small cyclonic systems, generated in the Mediterranean to the south of the Alps and cut from the Polar front, move into the West Balkans and become stationary they provide conditions so that powerful mesoscale convective systems can develop over the mountainous central Balkans including West Bulgaria. The convection feeds back the cyclonic circulation with fresh energy and thus helps to sustain the strong precipitation for as long as a couple of days.

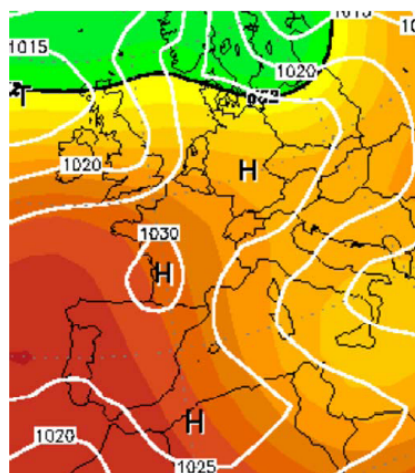


Figure 5.41: Height (dm) of geopotential surface 500 hPa in color and mean sea-level pressure (hPa, white contour), 11 May 1979.

5.3.2.4 Results

The expert analysis concerning the quality of the catalogue 2 types WLK, GWT and KRZ with several input variables is presented with 3 grades (1.0 for excellent, 0.5 – good and 0.2 – bad) in Tab. 5.14. The highest scores are given to classifications catalogues WLK28YRS01-U7-V7-Z9-Z5, GWT27-YR-S01-SP and KRZ09-YR-S01-SP-Y5. Overall, the classifications catalogues WLK, GWT, KRZ09-YR-S01-SP-Y5 and KRZ18-YR-S01-SP-Y5 (coloured in pink) can be assessed as excellent in total. The classification catalogues coloured in yellow can be assessed as good. The remaining catalogues included in the study can be classified as bad. We can conclude for both WLK and GWT classification catalogues that by changing the input variable and by increasing the catalogue number their applicability improves. Neither increasing the input variables nor the sequencing improves the applicability of the KRZ catalogue classification. The reasonable explanation is that the 4-day-sequence KRZ catalogue classification does not relate as much to the atmospheric circulation dynamics leading to heavy precipitation. The KRZ catalogue classification definition improves the catalogue 2 applicability for the winter season. However the same can not be said for the autumn season. The worst KRZ catalogue classification is related to the K5 input variable.

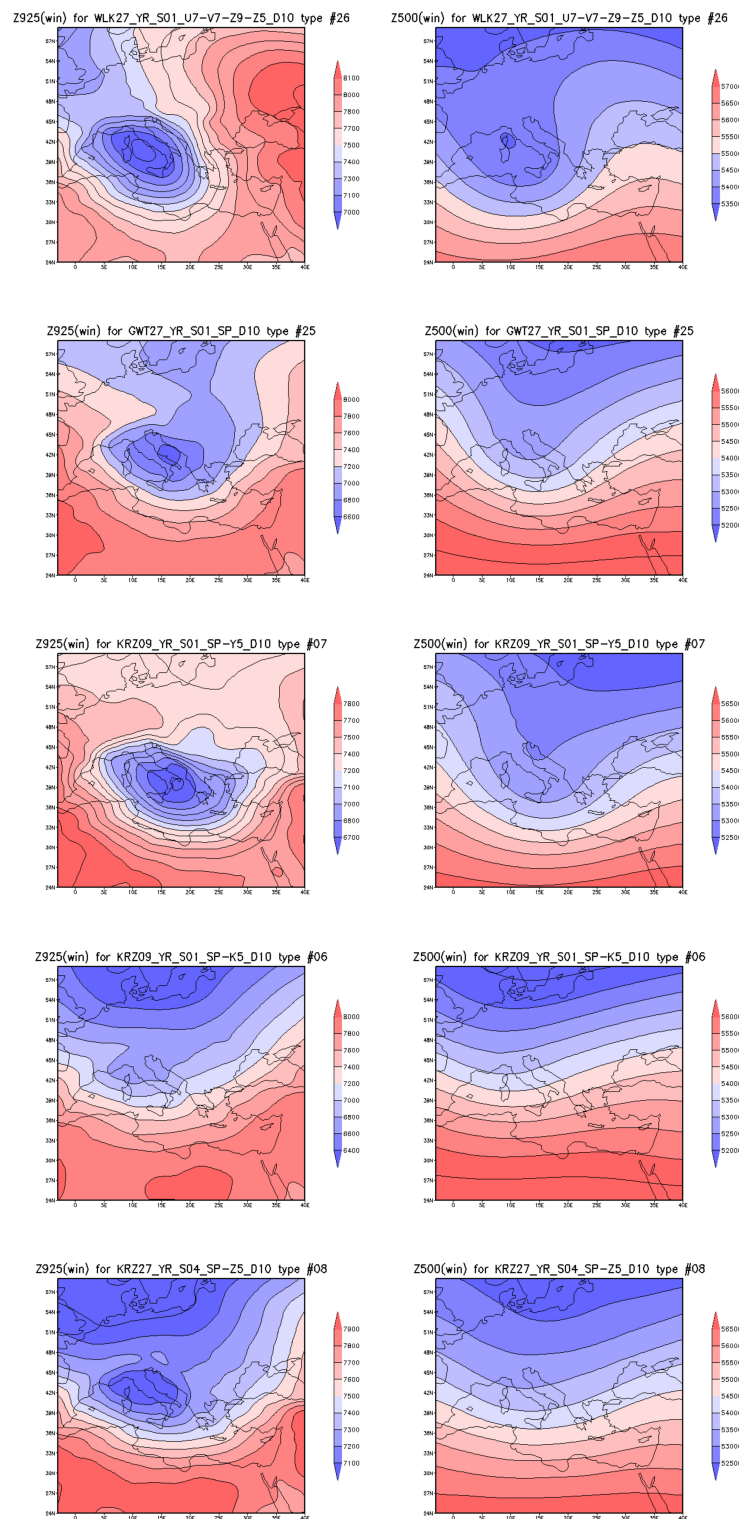


Figure 5.42: The catalogue maps that match the weather pattern of 2 December 1969 over Bulgaria (a heavy precipitation case with 24h-precipitation amounts between 60–99mm registered at 6 stations).

Table 5.14: Expert quality assessment of the COST733CAT v.2.0 WLK, GWT and KRZ classifications with several input variables.

<i>Classification</i>	<i>Winter</i>	<i>Spring</i>	<i>Summer</i>	<i>Autumn</i>
WLK28YRS01U7V7	1	1	1	1
WLK18YRS01U7V7	0.5	1	1	1
WLK9YRS01U7V7	0.5	1	0.5	1
GWT27YRS01SP	1	1	1	1
GWT18YRS01SP	1	1	0.5	1
GWT8YRS01SP	0.5	1	0.5	0.5
KRZ09YRS01SP	0.5	1	0.5	0.5
KRZ09YRS01SPK5	0.2	1	1	0.5
KRZ09YRS01SPY5	1	1	1	1
KRZ09YRS01SPZ5	1	1	0.5	0.5
KRZ09YRS01SPK5	1	0.5	0.2	0.5
KRZ09YRS04SP	0.5	0.5	0.5	0.5
KRZ09YRS04SPK5	0.2	0.5	0.5	0.5
KRZ09YRS04SPY5	1	1	0.5	0.2
KRZ09YRS04SPZ5	1	0.5	0.5	0.5
KRZ09YRS04SPK5	1	0.2	0.5	0.2
KRZ18YRS01SP	1	1	0.2	0.2
KRZ18YRS01SPK5	0.2	0.5	0.5	0.2
KRZ18YRS01SPY5	1	1	0.5	0.5
KRZ18YRS01SPZ5	1	1	1	0.5
KRZ18YRS01SPK5	0.5	0.5	0.5	0.5
KRZ18YRS04SP	1	0.5	0.5	0.2
KRZ18YRS04SPK5	0.2	0.5	1	0.2
KRZ18YRS04SPY5	1	0.5	0.5	0.2
KRZ18YRS04SPZ5	1	0.2	0.2	0.2
KRZ18YRS04SPK5	1	0.2	1	0.2
KRZ27YRS01SP	1	1	0.2	0.5
KRZ27YRS01SPK5	0.2	0.5	1	0.2
KRZ27YRS01SPY5	1	1	0.2	0.5
KRZ27YRS01SPZ5	1	0.5	0.5	0.2
KRZ27YRS01SPK5	0.5	0.5	1	0.2
KRZ27YRS04SP	1	0.5	1	0.2
KRZ27YRS04SPK5	0.5	0.5	1	0.2
KRZ27YRS04SPY5	0.5	0.5	0.2	0.2
KRZ27YRS04SPZ5	0.5	0.2	0.2	0.2
KRZ27YRS04SPK5	1	0.2	1	0.2

In addition we consider the heavy precipitation case with precipitation amounts between 60–99mm registered at 6 stations on 2 December 1969 related with the weather pattern given in Fig. 5.37. From the plots in Fig. 5.42 we can see that WLK28YRS01-U7-V7-Z9-Z5, GWT27-YR-S01-SP, KRZ09-YR-S01-SP-Y5 match well the synoptic-scale circulation pattern at that date. Improvement of the applicability of the classification catalogues can not be achieved by increasing the variables input and sequencing e.g., KRZ09-YR-S01-SP-K5 and KRZ27-YR-S04-SP-K5.

5.3.2.5 Summary and Conclusion

The quality of the COST733CAT v.2.0 circulation types WLK, GWT and KRZ classifications D10 domain is assessed with regards to large synoptic-scale circulation over Europe associated with heavy precipitation in Bulgaria. Overall, the classifications catalogues WLK, GWT, KRZ09-YR-S01-SP-Y5 and KRZ18-YR-S01-SP-Y5 match well the synoptic-scale circulation and can be assessed as excellent in total. The study shows that improvement of the classification catalogues KRZ can not be achieved by increasing the input variables and sequencing due to the atmospheric circulation dynamics leading to heavy precipitation.

5.3.2.6 Recommendations

- **Family of algorithms**
The best classifications for D10 domain concerning heavy precipitation in Bulgaria are based on the WLK, GWT, KRZ09-YR-S01-SP-Y5 and KRZ18-YR-S01-SP-Y5.
- **Number of classes**
Increasing the number of classes does not improve the applicability.
- **Sequencing**
Single day (YR-S01) and 4-day-sequence (YR-S04) classifications were considered. The 4-day-sequence (YR-S04) classifications do not improve applicability.

5.3.3 Circulation types associated with freezing precipitation over Bulgaria

Authors: Dimitar Nikolov, Christoph Beck, Andreas Philipp and Plamen Neychev

5.3.3.1 Introduction

Freezing rain events are not very often observed on the territory of Bulgaria but they could be surprisingly severe. The most affected regions are in the north, and especially in the northeastern part of the country. This severity is determined by the simultaneously influence of two factors: very intensive Mediterranean cyclone, passing south of the country, and a strong cold advection from north or northeast. This situation is very favourable for freezing rain in the northern part of Bulgaria. The southern regions are protected from the cold advection by the mountain Stara planina, which crosses through the whole territory of the country from east to west. Our previous investigations have revealed the most common synoptic configuration during freezing rain events. The purpose of this study now is to see how well these situations are represented in the selected by COST733 classification of circulation patterns for domain 10.

5.3.3.2 Data and Methods

We have used data for freezing rains from 2 representative meteorological stations in northeast Bulgaria for the period 1957–2002. During this period 79 freezing rain events were registered. We have presented them as Yes (1) and No (0) event and combined with the ERA40 data for Domain 10. We have used the COST733CAT 2.0 and the software developed by WG2 ([PHILIPP et al., 2010](#)) – trying to have at least one classification from the main methods of classifications. The classifications tested so far are: GWT, DKM, KMN and PXE with different number of classes. Because of the magnitude of the temperature in determination of the type of precipitation, we have used also multivariate classification including the sea level pressure, precipitation and air temperature at 850 hPa. Additionally we have given different weighting factors of these parameters according to their importance. To each classification we have also determined the differences between the classes and the corresponding event distributions, the standard deviation of the classes and the event groups, the within-type standard deviation (WSD) and the correlation coefficients for each event class. Summary of these results are presented below. The centroid plots from the classes with highest frequency are finally compared with the reanalysis from NCEP and archive synoptic maps.

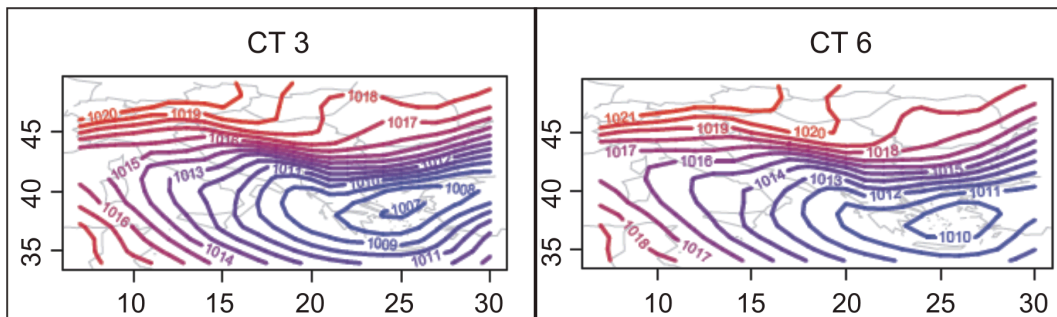
5.3.3.3 Results

The first method which has been tested is GWT prototype – large scale circulation types ([BECK et al., 2007](#)). This classification uses prototype patterns and Pearson correlation coefficients between each field. This classification has been tested for 9, 18 and 27 (see the table below) number of classes, showing that the higher number of classes only slightly increases the relative frequency of the events into classes. Generally the freezing rain events are evenly distributed into the circulations classes with very low frequency (Tab. 5.15), which should mean that they are not well recognized by this method.

Table 5.15: Relative frequency of the freezing rain events for GWT27.

<i>CT1</i>	<i>CT2</i>	<i>CT3</i>	<i>CT4</i>	<i>CT5</i>	<i>CT6</i>	<i>CT7</i>	<i>CT8</i>	<i>CT9</i>
0.00	0.004	0.00	0.00	0.03	0.05	0.03	0.01	0.00
<i>CT10</i>	<i>CT11</i>	<i>CT12</i>	<i>CT13</i>	<i>CT14</i>	<i>CT15</i>	<i>CT16</i>	<i>CT17</i>	<i>CT18</i>
0.00	0.004	0.01	0.003	0.005	0.009	0.005	0.00	0.005
<i>CT19</i>	<i>CT20</i>	<i>CT21</i>	<i>CT22</i>	<i>CT23</i>	<i>CT24</i>	<i>CT25</i>	<i>CT26</i>	<i>CT27</i>
0.00	0.005	0.012	0.024	0.01	0.005	0.021	0.00	0.00

The second type of methods that has been tested is based on non-hierarchical cluster analysis. We have used KMN (kmeans – conventional k-means with random seeds) and DKM (dkmeans). We have tested this method of classification for various numbers of classes and with additional parameters. The main field used here is the sea level pressure (slp) and the additional parameters are precipitation (prc), the 850 hPa air temperature (tmp) and information about the event (ice) – yes or no. Different weights have been given to all these parameters according to their magnitude. Now we have achieved small number of classes with icing but instead well-defined freezing rains classes – some of the centroids show very high frequency and some of them are predominant for the given class and have frequency very close to 1. Again the results are better when increasing the number of classes. The best results have been achieved with the following combination of parameters and weights: slp – 2.0; prc – 1.0; tmp – 1.0 and ice – 0.03. The main freezing rain centroids for this classification are given below (Figs. 5.43–5.45).

**Figure 5.43:** DKM11_prc.w0.03 classes with the highest relative frequency of the events – left CT 3 with 7.3% and right CT 6 with 7.0%.

These results generally correspond to the results of [LATINOV and NIKOLOV \(2002\)](#), where only 4 types of freezing rain situations were recognized. Below are presented the corresponding plots in Fig. 5.46 for the best results so far – CT 15 for KMN27_slp2.0_prc1.0_tmp1.0_ice0.03.

5.3.3.4 Summary and Conclusions

Four methods of classifications have been tested in an attempt to find a common circulation type for freezing rain events over Northeast Bulgaria. Increasing the number

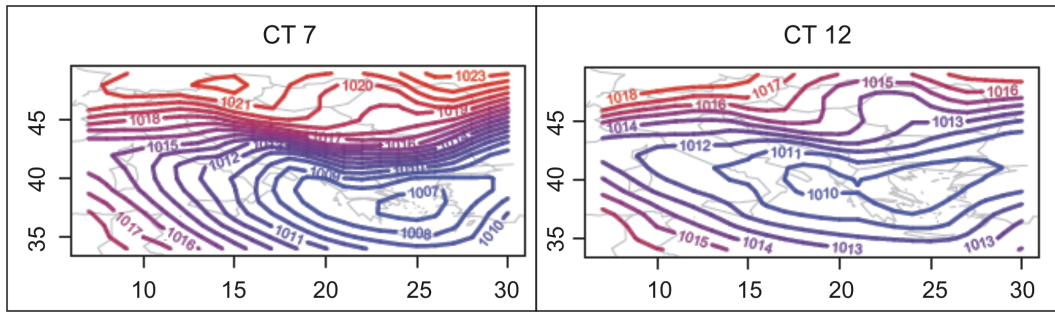


Figure 5.44: DKM27_prc.w0.05 classes with the highest relative frequency of the events – CT 7 and CT21 both with 100%.

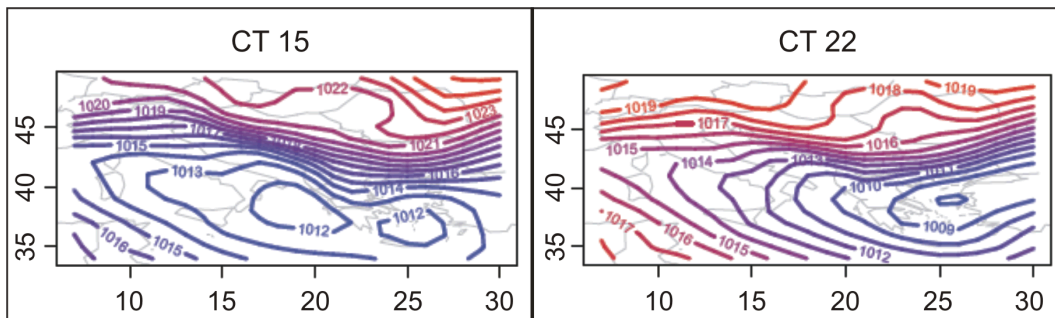


Figure 5.45: KMN27_slp2.0_prc1.0_tmp1.0_ice0.03 classes with the highest relative frequency of the events – left CT15 with 100% and CT22 with 10.0%.

of classes yields a better result and including more parameters and weight factors seem to be the best way to find the typical freezing rain patterns. The best results until now have been achieved with the KMN classification with 27 numbers of classes and sea level pressure, precipitation, 850 hPa air temperature and icing event as additional parameters with corresponding weight factors – KMN27_slp2.0_prc1.0_tmp1.0_ice0.03. This method has revealed up to four types of freezing rain circulation patterns with one predominant type. This study will be continued with a more extended classification effort and additional data for freezing rains e.g. air temperature, precipitation amount etc.

5.3.3.5 Recommendations

- **Family of algorithms**

On the bases of the tested methods only: it seems that GWT is not suitable for classification of freezing rains; CKM and DKM have shown very good results.

- **Number of classes**

Increasing the number of classes yields to significant improvement of the separation of the freezing events.

- **Input variables**

Additional variables have been shown to be helpful for refining the separation.

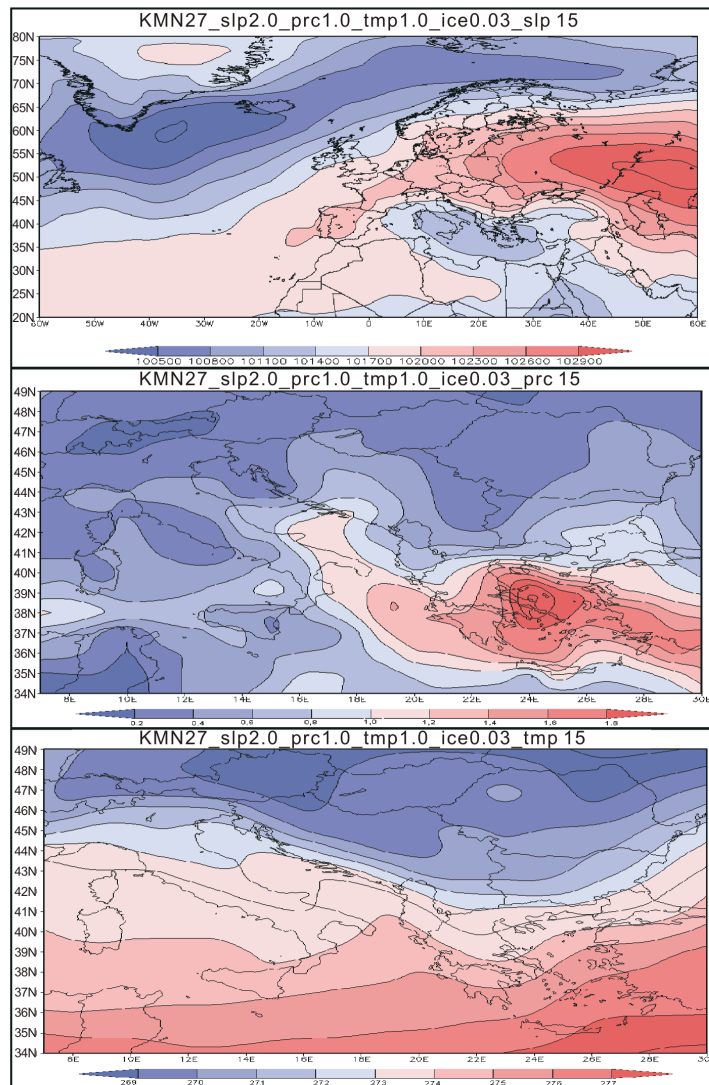


Figure 5.46: Upper panel: Sea level pressure field for the CT 15 for KMN27_slp2.0_prc1.0_tmp1.0_ice0.03; Middle panel: Precipitation field for the CT 15 for KMN27_slp2.0_prc1.0_tmp1.0_ice0.03; Lower panel: 850 hPa air temperature field for the CT 15 for KMN27_slp2.0_prc1.0_tmp1.0_ice0.03

5.3.4 Links between circulation types and regional hydrological drought in north-western Europe

Authors: Anne K. Fleig and Lena M. Tallaksen

5.3.4.1 Introduction

Hydrological drought is defined in a relative way as a regional deficit in surface water or groundwater over an extended period of time as compared to normal conditions. In this study, the focus is on streamflow droughts. In order to mitigate the negative effects of drought, forecast severe events or study hydrological drought characteristics for future climate scenarios, a good understanding of the hydro-climatological processes causing severe droughts is essential. In particular, the larger-scale processes leading to regional droughts are here of interest, as the severity of hydrological droughts increases with drought duration and affected area.

Streamflow responds to the combined effects of meteorological and hydrological input, transfer and storage processes, and hence integrates over variables, processes, time and space. The most important variables for hydrological drought development are precipitation and air temperature (i.e. evapotranspiration loss). However, spatial and temporal variability of precipitation and temperature are high due to local climate and physiological characteristics. For the study of larger-scale processes leading to drought, atmospheric pressure data in general are a good alternative as they characterise synoptic patterns rather than local-scale variability. The use of weather and circulation types (CTs) has the additional advantage of describing the atmospheric situation over a region as a single nominal variable and at the same time showing strong correlations with many local meteorological variables, which may be important for drought development. In this study, links between CTs and regional hydrological drought in north-western Europe (Denmark and Great Britain) were investigated, with the following two main objectives:

- Comparison of the suitability of the 73 circulation type classifications (CTCs) in COST733cat 1.2 (COST733CAT) with respect to regional drought studies (FLEIG et al., 2010a);
- physical interpretation of drought related CTs (FLEIG et al., 2010b) as identified with the Objective Grosswetterlagen (OGWL).

5.3.4.2 Data and methods

The study region, encompassing Denmark and Great Britain, lies in a temperate-humid climate zone and shows varying surface hydrology caused by regional variations in climatological and hydrogeological properties. Regional hydrological droughts were studied for four homogeneous regions in Great Britain and two in Denmark. The used Regional Drought Area Index (RDAI) is based on deficits derived from daily river flow series and gives the proportion of the drought affected area within a region (FLEIG et al., 2010b). The total area of a region and the drought affected area are quantified in terms of the sum of all or only the drought affected basin areas in a region, respectively. Drought events are defined as periods during which $RDAI > 0.7$.

All 73 CTCs included in the COST733CAT-1.2 derived on domain 00 covering Europe and the eastern North Atlantic (30°–76°N; 37°W–58°E) have been used. This domain has been chosen as regional droughts are to be studied over large areas, with the option to later-on extend the study to all of Europe. The subset of COST733CAT-1.2, which includes the 42 CTCs derived by the 14 classification procedures run for 9, 18 and 27 CTs is here referred to as COST733CAT(42). For each of the six regions, CTs associated with hydrological drought development were identified based on frequency anomalies of the CTs during the periods leading up to the five most severe drought events as compared to the average frequency of a given CT for the same period of the year over the entire data record (1964–2001). A period equal to the regional hydrological response time, d_{reg} , (45–210 days) preceding the drought plus the 20 first days of the drought was used. All CTs with a net positive frequency anomaly over the five droughts were considered to be associated to drought development. The performance of a given CTC was assessed by correlation between annual series of the number of drought days during the summer half-year, N_d , and the corresponding total frequencies of all drought related CTs during either the summer half-year or the summer plus previous winter half-year, depending on the regional hydrological response time. The number of regions for which a CTC obtained significant correlations at the 99% confidence level served as performance criterion, C , ranging between 0 and 6 (i.e. no to all regions).

i.) Fig. 5.47 shows the performance of the 73 CTCs ordered according to their general classification concept (also called “algorithm family”). The best performing CTCs were the OGWL, the objective Second Generation Lamb Weather Type Classification (LWT2) with 18 CTs and the objective Wetterlagenklassifikation (WLK) with 40 and 28 CTs. In general, CTCs with more CTs (≥ 27) were found to perform better than CTCs with less CTs (≤ 18), and CTCs derived by automated classification procedures using predefined CTs (either based on thresholds or on an originally subjective classification, e.g. the OGWL) performed better than those defining CTs by PCA or an optimization algorithm. CTCs derived using a leader algorithm and the manual CTCs performed worst. Only eight classification procedures derived for a similar number of CTs but different input variables were available. Based on those, no consistent influence of input variables on the performance of a CTC was found. There is, however, some indication, that the use of pressure data from two height levels instead of one improves the performance of a CTC, which should be investigated further using COST733CAT-2.0. Further mean performance values were derived for COST733CAT(42). Threshold based CTCs with a high number of CTs and PCA based CTCs with 9 CTs were found to perform well. This may suggest that PCA based classification procedures can capture well the major atmospheric patterns (i.e. differentiating ± 9 CTs) associated with regional hydrological drought development, whereas predefining CTs considering expert knowledge may add potentially important regional climatological information, which is not well captured by purely mathematically-derived CT definitions. The threshold based classification procedures as well as the best performing PCA based procedure (P27) consider the main air flow characteristics of zonality, meridionality and cyclonicity, and it is suggested, that the performance of a CTC may be related to a realistic representation of CT characteristics, e.g. in terms of seasonal variation in CT-frequencies (results not shown) and the air flow characteristics.

ii.) Using the OGWL classification, it was found that the dominant drought-yielding CTs varied between the six regions. High pressure systems centred over the respective region were most frequently associated with droughts, as well as CTs with a southern (S, SE or SW) airflow over the British regions and a northern (N, NE or NW) air-flow

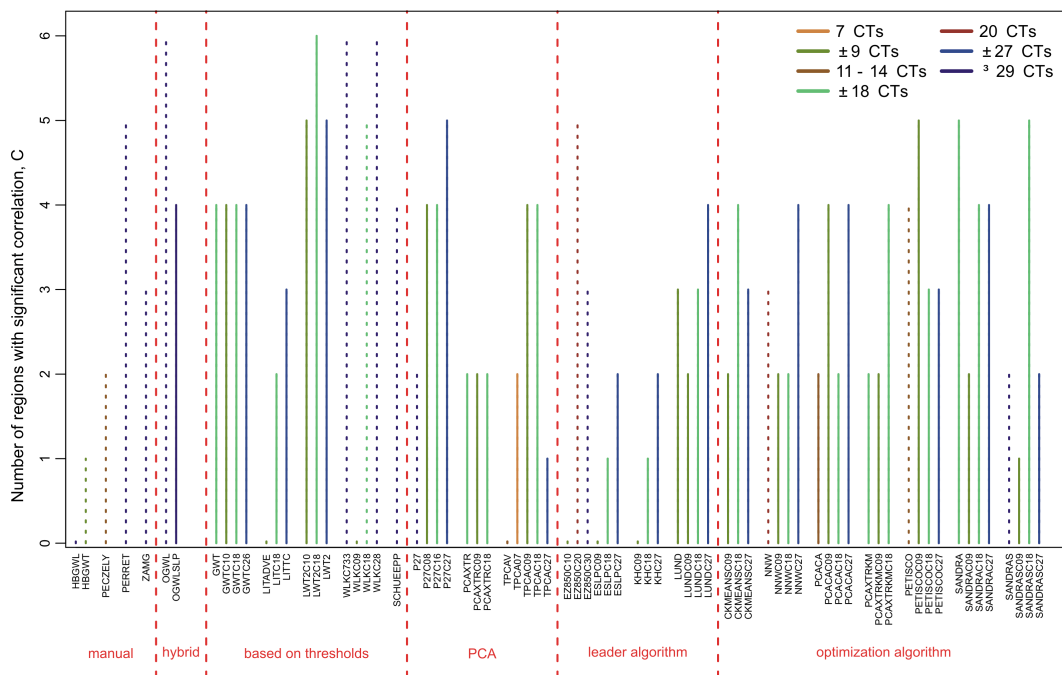


Figure 5.47: Performance, C , of the 73 CTCs ordered according to their general classification concept (red text). CTCs not included in COST733CAT(42) are written in italic and results for CTCs using input variables other than sea level pressure are plotted as dotted lines [modified after FLEIG et al. (2010a)].

over the Danish regions. As such the identified CTs represent situations with air masses coming from land areas, which are during summer typically drier and warmer than air masses coming from sea areas. Furthermore, the location and relative proximity of high (H) and low (L) pressure systems to the region are relevant factors. For instance, southern air flows over Denmark are rarely associated with drought development, as the air masses then are mainly influenced by a nearby L in the west (when using the OGWL classification). Northern flows, on the other hand, are related to a H in the west, which may evolve into a CT representing a H over Denmark during the following days due to the general eastward movement of pressure systems.

5.3.4.3 Conclusions

The applied method to identify drought related CTs seems to be an appropriate approach as indicated by the physically meaningful results for the OGWL. The influence of several CTC properties on the CTC performance remains to be investigated further. This includes the applied input data, domain size and the use of sequencing. It has for instance not been tested, whether the number of classes (CTs) preferable for regional hydrological drought studies depends on domain size or on the extent of the study region.

5.3.4.4 Recommendations

- **Family of algorithms**

Automated CTCs using predefined CTs are preferable. This includes the threshold based and hybrid CTCs such as the OGWL. (Hybrid CTCs are based on a

subjective CT definition but the daily CT assignment is automated and hence objective.)

- **Number of classes**

In general, CTCs with a higher number of classes (i.e. ≥ 18 classes) are preferable, with the exception of PCA based CTCs, when a smaller number of classes is preferable (i.e. 9 classes).

- **Input variables**

Not tested for COST733CAT v2.0. Based on COST733CAT v1.2 with only few cases to compare, no consistent dependency on input variables was found. It is indicated, however, that using pressure data from two height levels (i.e. at sea level or 925 hPa and at 700 or 500 hPa) may be preferable over either sea level or higher level data only.

- **Seasonal**

Not tested. A seasonal CT definition is not applicable to this study, as CT patterns are assumed to be consistent throughout the year.

5.3.5 Links between atmospheric circulation and flood events in Europe

Author: Christel Prudhomme

5.3.5.1 Introduction

Flooding is a natural hazard with damaging consequences to the society, both in terms of human impact and economical damage (BARREDO, 2007). While a direct link between flooding and heavy rainfall is easy to draw, the intensity, temporal sequencing and spatial distribution of precipitation spells are important due to the non-linear transformation between rainfall and runoff as the catchment (soil, geology, topography, vegetation and land cover) plays a significant role in delaying and redistributing water (WARD and ROBINSON, 2000). This suggests that specific synoptic patterns could be linked to the occurrence of floods as they are associated with different rainfall mechanisms. The advance of computing science resulted in the development of numerous algorithm to characterise and classify atmospheric circulations (HUTH et al., 2008), including the understanding of atmospheric circulation dynamics and circulation-climate relationships (JACOBEIT, 2009). It is hoped that this will also facilitate the understanding of large-scale climate-flow (and in particular flood) relationships. While association of Circulation Types (CT) and precipitation variation has been researched extensively and links used in weather forecasts (OBLED et al., 2002; O'HARE et al., 2005), direct links between weather type and extreme floods are, however, rarely investigated at a large spatial scale. This case study aims to fill this research gap, and is a first step towards evaluating whether some large-scale circulation patterns systematically show a strong link with flood occurrence across Europe. The analysis systematically assesses a number of automatic classifications to identify if some show clear discrimination power for flood events. If such relationships can be identified, they could be used as proxy for evaluating flood occurrence using atmospheric circulation, but also could be used to assess current General Circulation Models and their ability to reproduce flood-generating atmospheric patterns.

5.3.5.2 Data and methods

The study was conducted on 488 river basins across Europe. Daily river flow data was obtained from the Global Runoff Data Centre (<http://grdc.bafg.de/servlet/is/Entry.987.Display/>), the European Water Archive (<http://www.eea.europa.eu/data-and-maps/data/external/european-water-archive>), the UK National River Flow Archive (<http://www.ceh.ac.uk/data/nrfa/index.html>) and the French Banque Hydro (<http://www.hydro.eaufrance.fr/>). For each catchment, flood events were selected from the daily river flow according to the peak-over-threshold (POT) method (NADEN, 1993), where the largest n floods are selected, n being proportional to the length of the daily flow series. Here, the criterion is of POT3, i.e. $n = 3 \cdot Y$ where Y is the number of years of data. The independence criteria defined by BAYLISS and JONES (1993) were applied.

The Circulation Type catalogue v1.2 of the European COST733 Action was used for the analysis. Sixty three automatic CTCs are selected, all calculated from daily circulation fields (mostly sea level pressure) over the D00 domain. This set uses 18 independent classification methods, including methods based on Thresholds, Principal Component

Analysis, Leader algorithms and Optimization algorithms, but applied with different type numbers (closest to 9, 18 and 27 classes). The OGWLSLP automatic version of the Hess-Brezowsky Grosswetterlagen (JAMES, 2007) was also considered.

Links between flood event and CT occurrence were analysed following DUCKSTEIN et al. (1993). In order to incorporate the time-lag in the river basins, the indicators are calculated for a set of N^* days preceding the flood – here between 1 and 10 days were tested for N^* . Three indicators were considered. PI1 is the ratio between the relative number of days with pattern CTi in N^* days up to the flood ($n_1(i)$) and the frequency of the same CTi any day ($n_2(i)$ is the relative number of days with pattern CTi), with i the index of CTi for the given CTC with a total of C classes. Values greater (lower) than 1 indicate that CTi occurs more (less) frequently during flood days than in general. It is the same indicator as introduced by GOODESS and JONES (2002) and used in Case I.5 as PROPct/PROPtot. PI2 measures the conditional probability of finding at last k days out of N^* with CTi, given that a flood occurred on day zero: $PI2(i) = pr(CT = i \text{ for } \geq k \text{ days}, 0 \leq k \leq N^*)$.

RPI (Regional PI) evaluates the spatial coherence of the local relationships, defined by:

$$RPI(i) = \frac{\sum_{r=1}^B w_r \text{Score}_{PI}(i, r)}{B} \quad (5.6)$$

with $\text{Score}_{PI}(i, r)$ the score obtained by CTi for river basin r , B the total number of river basins, and C the number of classes of CTC. The scores are given according to the ranked $PI(i, r)$ standardised by the number of classes to allow comparison of relative performances of CTCs of different number of classes: $\text{Score}_{PI}(i, r) = 1/C$ for the lowest $PI(i)$ of r , and $\text{Score}_{PI}(i, r) = C/C = 1$ for the highest $PI(i)$ of r . For each CTi, there is one RPI per PI, i.e. for each N^* and k combination for both PI1 and PI2. w_r is a weight associated each catchment in a case of uneven spatial distribution of the dataset. The discussion focuses on the maximum RPI as it measures the spatial coherence of the CTi with the strongest relationship with flood events.

5.3.5.3 Results

When calculated over the whole year, WLKC (for 9, 18 and 27 classes) and TPCAC (for 9 and 27 classes) have a maximum $RPI(PI1_{year})$ equal to 1, indicating that for these catalogues, the same CT systematically leads to the largest $PI1_{year}$ for all river basins (Fig. 5.48). PETISCOC also shows high spatial coherence for 9 and 18 classes, but does not achieve the maximum score. The classifications with the least spatial coherence in the highest $PI1_{year}$ across Europe are LITADVE and KHC.

Except for the WLKC and TPCAC, greater spatial coherence is achieved for classifications with fewer classes (around nine: yellow – light grey), but classifications with 18 or 27 classes have comparable performances. The subjective OGWSLPC is not amongst the CTCs displaying the greatest spatial coherence in their flood-generating CT (best score of 18th highest $RPI(PI1)$ obtained for a 10-day period).

$RPI(PI2_{year})$ reaches the maximum of 1 only for two CTCs (Fig. 5.48), and WLKC remains one of the best performing algorithms with 3 catalogues amongst the top 5. There is generally no significant effect of the number of classes, and the same CTis are often associated with the highest $RPI(PI2_{year})$ for all considered duration.

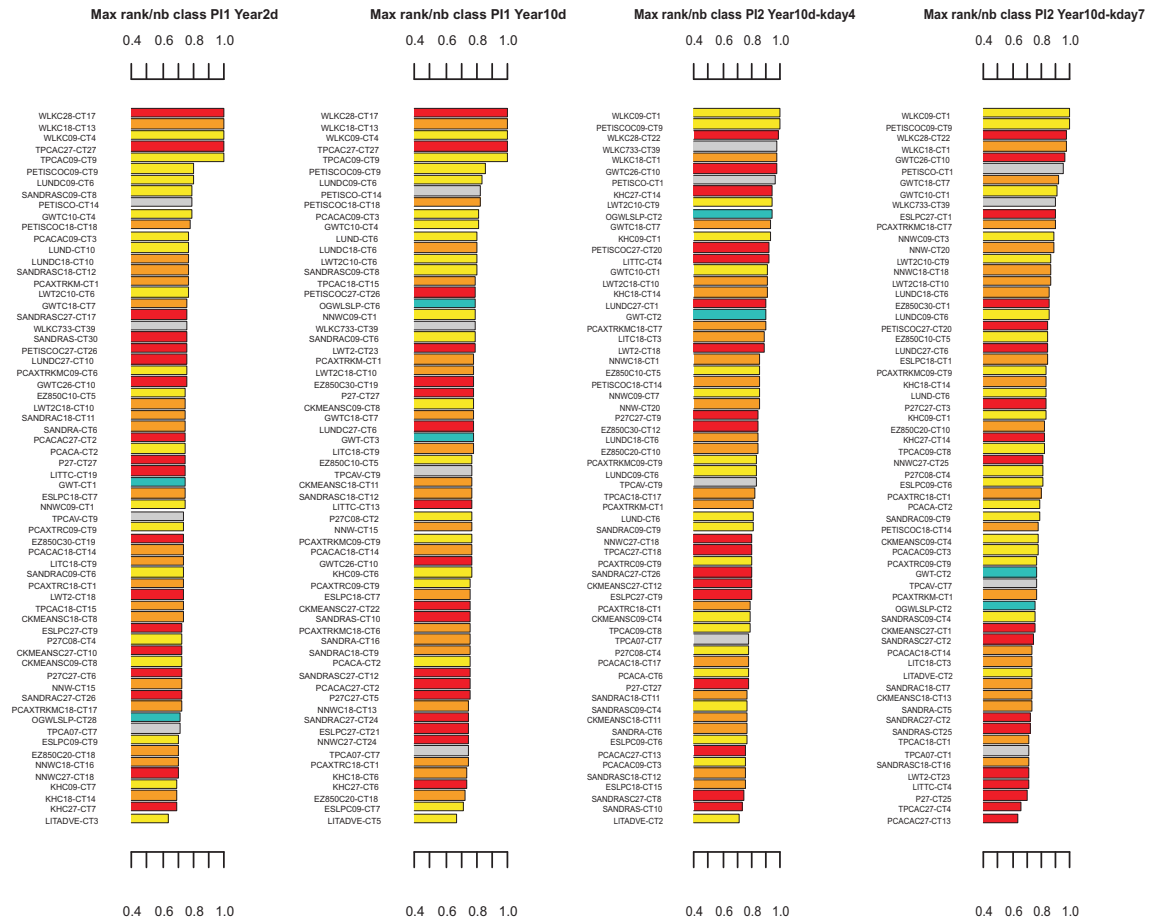


Figure 5.48: Maximum RPI(PI_{1year}) for all CTCs for (i) 2 days and (ii) 10 days. Maximum RPI(PI_{2year}) for all CTCs for (iii) 4 days persistence within 10 days (10lag-4pers); (iv) 7 days persistence within 10 days (10lag-7days). Bar size shows RPI for a given CTC-CTi. Bar colours distinguish classifications with ≈ 27 (red – dark grey), ≈ 18 (orange – grey), ≈ 9 types (yellow – light grey), other type numbers (grey), and subjective classifications (blue).

5.3.5.4 Conclusion

This analysis evaluated whether CTCs can inform on the occurrence of floods in Europe, and if the same few circulation types are systematically associated with flood events. Two local indicators were used to quantify these relationships, that measure if a CT occurs more frequently than usual prior/during a flood event, and if the persistence of a particular CT is generally followed by a flood event. A measure of the spatial coherence of the CT with highest local indicators was also calculated, helping comparing the relative performance of a number of CTCs. Antecedent conditions and the time-lag of the catchments were accounted for in calculating the indicators on a range of durations up to 10 days leading to a flood.

Relationships between flood occurrence on 488 river basins and CTCs were explored using a set of 64 classifications from the COST733CAT v1.2, all but one defined from automatic algorithms using ERA-40 mean sea level pressure patterns. Results show that at the river basin scale, some circulation patterns have significant positive frequency anomalies with flood occurrence, i.e. they occur more frequently before and during a

flood than in any other period. The persistence of the same CT is also found to have strong relationships with flood events, with some CT occurring more frequently several days before and during a flood than expected by chance alone. At the scale of Europe, the same conclusions could be made, with the same CTs showing the strongest links with flood occurrence throughout Europe. The number of classes used to define the catalogues was found to be of lesser importance than the algorithm used, and depending whether global frequency or persistence of CT were analysed, could give contrasting results. The results obtained from the automatic version of the Grosswetterlagen classification (OGWSLPC) were found in line with previous research made using the subjective catalogues. Comparison of all 64 CTCs showed that OGWSLPC did not contain the most spatial coherent CT in terms of flood relationships than others, and that persistence of its CT was not a good indicator of flooding. By contrast, other algorithms such as used to derive the WLKC and TPCAC were found to generally outperform any other classification, with strong frequency anomalies and persistence for up to 10 days before/during a flood.

5.3.5.5 Recommendations

- **Family of algorithms**

Difficult to conclude, but WLK and TPCA seem to show significant links with flood occurrence.

5.3.6 Atmospheric circulation type sequences applied to snow avalanches over the Eastern Pyrenees (Catalonia and Andorra)

Authors: Pere Esteban, Christoph Beck and Andreas Philipp

5.3.6.1 Introduction

Interesting examples for the application of circulation type classifications in natural hazards analysis exist e.g. for heavy snowfalls related to snow avalanches ([ESTEBAN et al., 2005](#)) or erosion in agricultural areas ([EKSTRÖM et al., 2002](#)). For several types of extreme events it is not adequate to analyse them only on short time scales (hours-days). But it is necessary to also consider longer sequences (several days to weeks) of different circulation configurations that facilitate the occurrence of some extreme natural phenomena. One example is snow avalanches, a natural hazard that is assumed to be affected by climate change in many mountainous areas. This contribution presents a synoptic analysis of snow avalanches in the Pyrenees, a massif very sensible to NAO fluctuations, and also to the Mediterranean airmass.

5.3.6.2 Data and methods

The cases used for the circulation type classification were extracted from Andorran newspapers for the period 1975–2005 ([GALLEGO, 2003](#)) and from the Catalan Avalanche Forecasting Service (IGC) database for the period 1985–2007. The classified cases cover the Catalan and Andorran Pyrenees and correspond to avalanches that have affected people (sometimes with deaths), roads or constructions.

Using the COST733CLASS ([PHILIPP et al., 2010](#)) calculations were made for 4, 6, 8, 10, 12 types and for 1, 3, 6, 9, 12, 15 days sequences of MSLP fields. These numbers of circulation types have been chosen based on expert knowledge on mountain weather and avalanche forecasting over the Pyrenees. Depending on varying combinations of preconditions and triggering factors for avalanche occurrence, varying lengths of daily sequences have to be considered. For example longer sequences have to be considered for avalanches that are due the formation of depth hoar over several weeks in advance to the occurrence of the avalanche triggered by human (mountaineers, snowmobilers,...) or natural (heavy precipitations, ...) factors. The methods that were used are the ones based on Principal Component Analysis (PCAXTR/PXE and TMODEPCA/PTT) and on clustering methods such as Kmeans (CKMEANS/CKM) or Simulated Annealing Clustering (SANDRA/SAN). Furthermore, 3 different maps were obtained for each type and classification for the period studied: Composite pattern of hazardous days with at least a 0.5 Pearson correlation to the centroid pattern, non-hazardous days with at least a 0.5 Pearson correlation to the centroid pattern, and the differences between both. Finally, frequencies considering different correlations to the type centroids were also obtained, permitting the calculation of the occurrence frequencies of the hazard days/sequences in relation to days/sequences with a similar spatial structure but without the occurrence of a hazardous event.

The quality of the classifications has been evaluated using some simple criteria:

- BTV – Between types variability: How many centroids show a correlation equal or higher to 0.8? The idea is to identify the capability of the classifications to obtain well separated types.
- WTV – Within type variability: How many hazardous days show a correlation lower than 0.7 to the centroid? With this rule, we identify the compactness of the clusters.
- OUT – Outliers: Are there cases with a correlation lower than 0.2 to the centroid? We identify days that are very different to the centroid, these are considered as outliers.

5.3.6.3 Results

Interpretation of the graphical outputs of OUT, WTV and BTV show that the best results are obtained by 8–10 type classifications. It is interesting, as one can expect, that as the number of clusters increases, it is more difficult to have outliers, and the easier it is to have compact groups. At the same time, more significant differences between groups are found with a decreasing number of clusters. Concerning the length of the sequences, the longer they are, the more internal variability there is in the groups. Considering all the rules-of-thumb commented on, TMODEPCA 6 clusters and 1 day sequence, TMODEPCA with 8 clusters and 3 days sequence, and TMODEPCA with 10 clusters and 15 days sequence were considered as the best classifications. An example of a CT is shown in Fig. 5.49.

5.3.6.4 Conclusions

- The analysis of the results shows that the application of classifications to days with occurrence of natural hazards is an interesting methodology for identifying the circulation patterns structure related to its occurrence. Application of sequences shows also promising results that clearly identify differences between more persistent patterns and more dynamic situations. The 15 days sequences classification related to avalanches clearly show this capability of applying sequences to classifications.
- Using a large amount of different classifications and some simple criteria of evaluation allows us to identify the best classifications in terms of number of types and length of the sequences. It is interesting to see that identification of long sequences (15 days) performs well for avalanche occurrence in the Eastern Pyrenees area.
- Northerly winds preceded by precipitation over the Pyrenees appear as one of the main precursors for avalanche accidents. These factors are directly related to the formation of wind slab accumulations. High temperatures related to periods with persistence of high sea level pressure values and heavy precipitation situations also appear as important factors for avalanche occurrence.
- Despite of the previous natural factors, the presence of mountaineers is necessary for having avalanche accidents with people injured, the main input of days for the database used. This is consistent with many sequences ending with days with anticyclonic conditions.

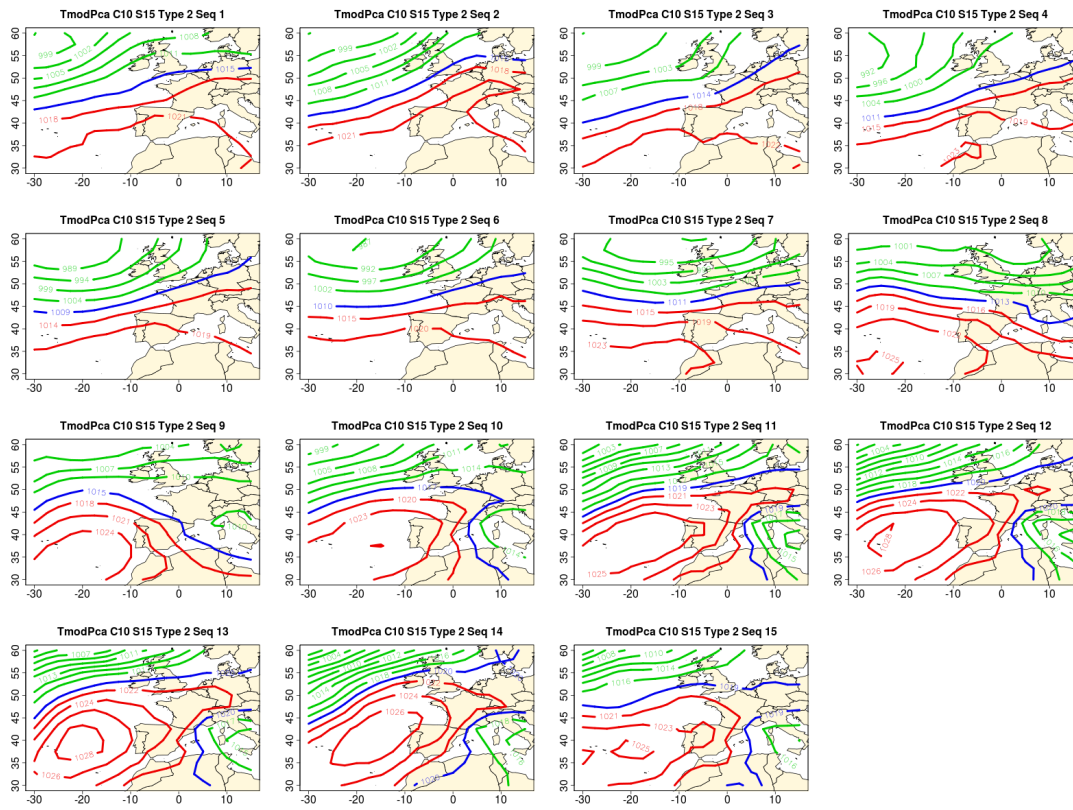


Figure 5.49: Circulation Type 2 with a 15 days sequence for TMODEPCA: Beginning of the sequence with high pressure conditions that change to westerly wind that facilitates the arrival of frontal systems to the Pyrenees between the 7th and the 8th day. Later, the Azores high move up to the Iberian Peninsula and generates, with the Genoa low, northerly winds over the Pyrenees. This northerly winds after the frontal system persist until the end of the pattern, becoming more and more related to anticyclonic conditions.

- The use of correlations to identify the most similar days to the centroids probably benefits to PCA methods, and mainly to TMODEPCA, to obtain the best results. This is probably related to the use of correlations also by this method for obtaining the final assignment of cases. Considering other similarity measures could be a very interesting research to be developed in the future. Furthermore, interesting applications on forecasting occurrence probability could be derived from the methodology and results presented.

5.3.6.5 Recommendations

- **Family of algorithms**

Only tested some methods of PCA based and optimization methods. Considering the simple evaluation methods, a better performance of PCA based methods can not yet be assumed.

- **Sequencing**

We would like to recommend testing the performance of sequences when one is interested in the analysis of natural hazards using circulation type classifications. For snow avalanches, interesting and interpretable long sequences has been obtained. Same procedure has been applied to heavy precipitation days (Catalan coast) and forest fires (Andorra) and also interesting results have been obtained.

5.3.7 Conclusions and recommendations – subgroup “Extremes”

The case studies presented in the chapter of extremes include analyses on a range of meteorological variables and meteorological impact, and consider very different space- and time-scales. This makes the generalisation of the conclusions very difficult. However, one common recommendation is that no one classification or one family of method is found to systematically have the strongest/ weakest links with any of the considered applications, and the ideal number of classes to define the classification is very linked to the application. This suggests that it is important to consider more parallel classification methodology. While WLK classification, which was originally designed for weather forecasting and is based on multi-input variables, seems to work particularly well for extreme wet events (both extreme precipitation and floods), further analyses need to be undertaken before the results can be generalised as this conclusion is not shared with other weather-related extreme applications. Finally, it seems that objective classifications, despite including expert judgment in the atmospheric processes, are often outperformed by automatic, objective classifications.

Table 5.16: Summary of the results from the case studies in the subgroup “extremes”. The symbols refer to: (1) – –/++: A lower/higher number of classes improve the results; (2) +/-: improvement/deterioration of the results; (3) ≈: no conclusive evidence for a significant impact and (4) blank: This criterion is not tested.

<i>Cat. version</i>	<i>Variable tested</i>	<i>Preferred algorithm (class)</i>	<i>domain (domain of interest)</i>	<i>nr. of classes</i>	<i>Add'l. input variable</i>	<i>Seasonal ?</i>	<i>Sequence ?</i>
2.0	Extreme precip.	WLK, GWT, KRZ		– –	–		–
2.0	Freezing rain	CKM		++	+		
1.2	Droughts	THR		++			
1.2	Floods	WLK, PCAC		≈			

5.4 Applications in forest fires

Forest fires have risen to the “top ten” rank of environmental problems of Europe, especially in the southern (Mediterranean) countries, due to the impact on the preservation of natural landscapes and their damages upon infrastructures, economic activities and human lives. Numerous factors of a very different nature intervene in the genesis of the forest fires, shaping them into an extraordinarily complex phenomenon with occurrences in almost all regions worldwide.

Climate is one of the most relevant underlying factors that explain the fire forest regime of a region. Each global biome is clearly linked to the large climate areas, differing from its structure and composition, and both features determinate the degree of flammability of the vegetation. But, as it is recognized worldwide, the interannual variability of occurrence of the forest fires experience large variations, even in those locations where they are recurrent phenomena, in response also to atmospheric forcing factors of diverse spatial and temporal variability. Additionally, even in those places where forest fires occur year after year, like the Mediterranean countries, most of the burned surfaces concentrate on a reduced number of catastrophic wildfires, whose occurrence may be explained by several atmospheric mechanisms, working at different temporal and spatial scales. Although the majority of the forest fires, particularly in Mediterranean areas, is a consequence of the human activities, at local scale, extreme weather conditions during the fire season (i.e., low relative humidity, high temperatures, strong winds) become a decisive factor for the ignition and propagation of the fires (rates of spread, magnitude, etc.). Temperature and air relative humidity control the degree of moisture of the dead fuels, while wind leads the propagation of the flames front once the ignition occurs, and regulates the quantity of liberated energy when providing oxygen to the fire.

Such discrete episodes are related to specific atmospheric circulation patterns, and several studies have addressed links between synoptic patterns and wildland fires. For example, [BROTAK and REIFSNYDER \(1977\)](#) made a synoptic classification of fifty-two major wildland fires in the eastern half of the United States. Three-fourths of the fires were found near surface frontal areas accompanied by a specific type of 500-hPa trough. Such troughs were associated with areas of strong winds and no precipitation at the surface. This synoptic situation is not common to forest fires in the Mediterranean climate zone, as will be discussed later.

In Portugal, [LOURENÇO \(1988\)](#) examined the synoptic conditions that accompanied eight major forest fires that occurred in 1986 in central Portugal. He found that in seven out of eight of the fires, the synoptic conditions were the same: an extension of the Azores High Pressure System to the center of Europe, which brought warm, dry easterly winds. It was found that fires began under easterly winds and ended after the winds shifted to westerlies, which brought moist, cool maritime air. He also indicated that fire weather conditions are extreme when the values of the temperatures are above those of the relative humidity (portrayed on the same scale). Moreover, [RAMOS and VENTURA \(1992\)](#) classified the synoptic conditions that prevailed in the four months of the fire season (June–September) in Portugal between the years 1987 and 1989, in the following six categories: Azores High Pressure System, an Azores High Pressure System extended toward Europe, a Thermal Low Pressure System from the Sahara extended toward the Iberian Peninsula, a Dynamic Low Pressure System, a Frontal Disturbance, and the flanks of an Atlantic High Pressure System. The two synoptic conditions in which fire risk was found to be extreme were extended Azores High Pressure System and the

elongated Thermal Low Pressure System from the Sahara. Additionally, [HOINKA et al. \(2009\)](#) analyzed the evolution of the synoptic- and meso-scale wind, temperature and humidity pattern during large (> 500 hectares) wildland fire events in Central Portugal. Five days in advance of a fire event, a strong positive anomaly existed in the surface pressure and in the 500 hPa geopotential field, both appearing to the west of the Iberian Peninsula and moving towards Brittany until lag zero. In advance of the fire event, the flow above Portugal came from the north, turning to easterlies at lag time zero and finally coming from the south-east during the post-event phase. Surface wind statistics and smoke plumes from wildland fires detected by satellites indicated a similar flow structure. Besides, their work also showed that the peak amount of burnt area occurred up to 3 days after the appearance of a thermal low. This suggested that in the pre-phase of a wildland fire, heated air is transported from the peninsula's centre towards Portugal. [PEREIRA et al. \(2005\)](#) discussed synoptic conditions associated with Portugal's wildland fires and investigated the link between winter and spring precipitation intensity and the wildland fire occurrence during the following summer. [TRIGO et al. \(2006\)](#) pointed out that during the devastating 2003 fire season in Portugal, the days with highest amounts of area burned were characterized by large anomalies in the surface maximum and minimum temperature, relative humidity, and wind speed and direction.

[LEVIN and SAARONI \(1999\)](#) found two types of atmospheric disturbances favourable for the development of forest fires in Israel: the North African ('Sharav') cyclone and the Red Sea trough, which are common during spring and autumn. Both systems carry hot, dry air from the deserts and were responsible for 55% of the burnt area from major forest fires in Israel and up to 33% of the major forest fires. In summer forest fires use to occur under the quasistationary system of the Persian Gulf trough, but fires did not spread as widely as those that occurred under the North African cyclone and the Red Sea trough systems.

In Southwestern USA [CRIMMINS \(2006\)](#) showed that wildfire activity can be strongly regulated by some critical fire-weather circulation patterns, representing broad south-westerly flow and large geopotential height gradients. Seasonal changes in relative humidity levels, strength of height gradient, and geopotential heights all modulate the relationship between these key circulation patterns and extreme fire-weather days.

Here, the following case studies are addressed:

- Circulation patterns and wildfire risk in the Northwest of Spain (Subsection [5.4.1](#)).
- Links between forest fires and CTs in Portugal (Subsection [5.4.2](#)).
- Synoptic control on wild fires in Greece (Subsection [5.4.3](#)).

All of these studies are focussing on the general explanatory power of the "basic" circulation patterns of wild (forest) fire occurrence around the Mediterranean. Other approaches as e.g. the role of soil moisture and precipitation in months preceding the wild fire season are out of scope of this report. Scientists interested in these particular phenomena are advised to check the above-mentioned references and references herein.

5.4.1 Circulation patterns and wildfire risk in the Northwest of Spain

Author: Domingo Rasilla Alvarez

5.4.1.1 Introduction

Daily weather variability is a major factor affecting the behaviour of wildfires. A better knowledge of the fire climate will enable fire managers to predict severe fire events in advance so that prevention programmes, prepared systems and mitigation activities can be implemented in a timely and effective manner. Linking atmospheric circulation at synoptic scale, weather conditions influencing fires at regional scale and the occurrence of very large forest fires becomes a necessary task in order to get a comprehensive characterization of the phenomena.

The first study ([RASILLA ÁLVAREZ et al., 2010](#)) presents an analysis of the atmospheric conditions associated with extreme weather and very large wildfires in Spain, combining the local response in terms of fire-favouring weather to the large scale forcing. Specific objectives were

- 1 to derive an objective daily catalogue of circulation patterns based on gridded 850 hPa geopotential heights for the Iberian Peninsula region;
- 2 to assess the control of local meteorological conditions that are directly related to fire behaviour – wind speed, temperature and relative humidity – by the atmospheric circulation within this synoptic climatological framework;
- 3 to evaluate the performance of each circulation type in order to discriminate the magnitude and spatial patterns of a daily fire risk index;
- 4 to identify the most common circulation patterns associated with the ignition of the largest forest fires in Spain, their efficiency and possible causes of internal variability.

A more specific analysis of wildfires was conducted on Northwestern Spain (Galicia and the provinces of León and Zamora), a region which accumulates more than 30% of the wildfires and 20% of the burned surface occurred in Spain since 1968 ([GARCÍA CODRON and RASILLA ÁLVAREZ, 2006](#)). Socio-economic (fire as a cultural tool, abandonment of traditional management) and demographic factors (rural depopulation) explain such fire activity, which shows two seasonal peaks, in coincidence with atmospheric conditions favourable for burning. For this study, the two main objectives are:

- 1 To analyze the temporal evolution of the summer forest fires in NW Spain.
- 2 To identify the most favourable atmospheric conditions for fire activity at different temporal (daily, seasonal) and spatial (province) scales.

5.4.1.2 Data and methods

Two types of databases are used: observed and modelled data. The former contains (a) data of ignition, detection time, burned surface and location of each wildfire that burn

more than 1500 h in any place of Spain (Dirección General de Biodiversidad, Gobierno de España) and (b) daily fire weather risk indices (Canadian Forest Fire Index) calculated from synop reports obtained from meteorological stations extended through the Iberian Peninsula, southern France and Northern Africa (maximum temperature, relative humidity, wind speed and precipitation) from the GLOBALSOD database (NCDC, <ftp://ftp.ncdc.noaa.gov/pub/data/g sod/>). The latter contains the large-scale circulation data obtained from the REANALYSIS/NCEP database. Fields of geopotential heights (850 hPa), relative humidity, air temperature, and meridional and zonal wind components at 12 UTC were extracted from a window approximately centred over the Iberian Peninsula. The 850 hPa level was chosen because it is closely representative of the surface conditions, while minimising distortion from local effects, since it is higher than most Iberian topographic features. Additionally, the 12 UTC time matched the mid-day peak in extreme fire-weather conditions.

A computer-assisted classification procedure, based on multivariate statistics (PCA and clustering, referred to as “CAP” in the COST733CLASS software), was used to derive an objective daily catalogue of circulation patterns based upon the gridded 850 hPa geopotential heights for the Iberian Peninsula region. As basic steps in the classification procedure, a preprocessing of the original data was applied to enable a year-round output, but preserving the spatial differences within the pressure fields. Principal Component Analysis of the filtered data provided additional filtering, reducing the multicollinearity of the database. The optimum number of groups and their centroids were obtained through a Ward’s clustering algorithm, while, finally, an agglomerative K-means procedure refined the final classification. Composite average fields of 850 hPa geopotential heights and wind vectors, and anomaly fields of 850 hPa relative humidity and 850 hPa air temperature, accompanied by anomalous spatial standardized (z-scores) fire weather risk index fields corresponding to each circulation pattern were constructed in order to test the accuracy of the atmospheric mechanisms within each circulation pattern (Fig. 5.50).

In NW Spain a different approach was conducted:

- 1 Regionalization of seasonal (JAS) forest fire activity by CAP.
- 2 Categorization of fire risk days. Calculation of values of the Canadian Forest Fire Weather Index (FFWI).
- 3 Comparison between daily values of FFWI, circulation patterns and burned surface.
- 4 Comparison between seasonal burned surface and long-term climatic anomalies (scPDI).

5.4.1.3 Results

Four from six clusters (circulation patterns) have been identified as the most effective circulation patterns in generating high levels of weather-related fire risk. Each pattern shows substantial region-wide differences in the magnitude of weather-related fire risk conditions, corresponding to combinations of controlling climatic factors. Two of them are characterized by the largest temperature and relative humidity anomalies, but moderate easterly and southeasterly flows; they are responsible for most of the extreme fire days occurred in the western regions of the Iberian Peninsula. Two other situations

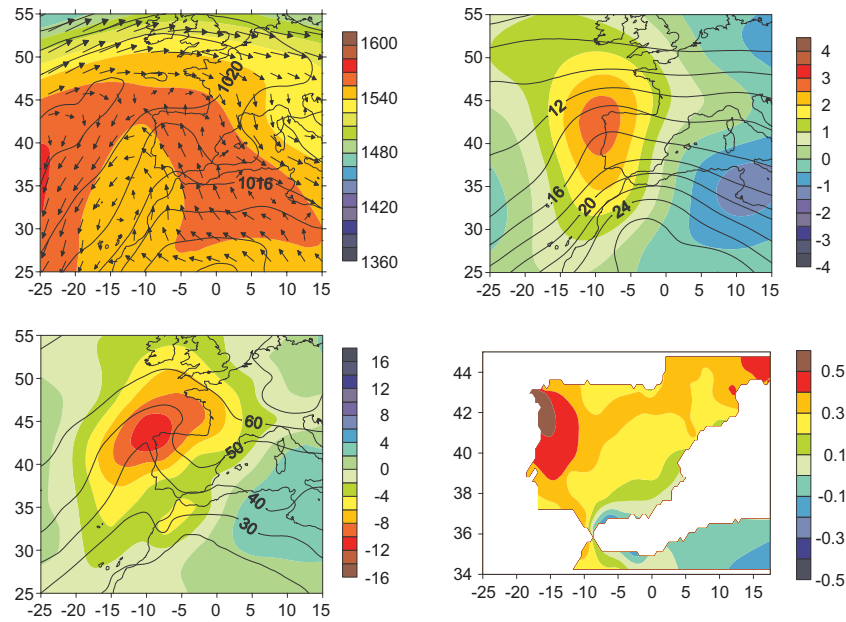


Figure 5.50: Composite and anomaly fields of 850 hPa relative humidity (%), upper panel, contour line) and 850 hPa air temperature (°C, lower panel, contour line) and anomalous spatial standardized (z-scores) FWI fields corresponding to the most dangerous circulation pattern in terms of wildfire risk.

display a more restrictive spatial pattern of surface weather-related fire risk conditions, centred along the Mediterranean seaboard. Here, a different dynamic mechanism explains the extreme levels of fire risk: strong downslope winds accompanied by low relative humidity values, more effective than temperature in elevating the weather-related fire risk levels.

- 1 In coastal Galicia, extreme fire seasons occur when conditions are much drier than normal, capable to enhance the fuel flammability of a usually humid environment; besides, the number of forest fires and their magnitude is mostly linked to one singular atmospheric circulation pattern which triggers high-risk weather conditions (easterly and southeasterly flows promoting a severe warming and drying).
- 2 Conversely, in northern Meseta, which suffers a higher fire risk because the warm and dry summer conditions, most of the forest fires, affecting shrub vegetation, tend to occur after relatively wet (winter) years. Such conditions support the growth of fine fuels that quickly dry out during the summer season, not requiring extreme weather conditions to initiate large forest fires in this area.

In both regions, two circulation patterns were responsible for most of the extreme forest fires risk and the largest (> 500 hectares) forest fires in the area, but showing geographical differences. CP2 is particularly relevant along the coastal area (51% of the extreme risk days) but represents only 20% of those days in the inner zone. Conversely, CP 4 accounts for more than 41%, days in the Meseta, followed by CP2 (Fig. 5.52).

The same geographical pattern is observed with more detail if the occurrence of large wildfires is analyzed (Fig. 5.53).

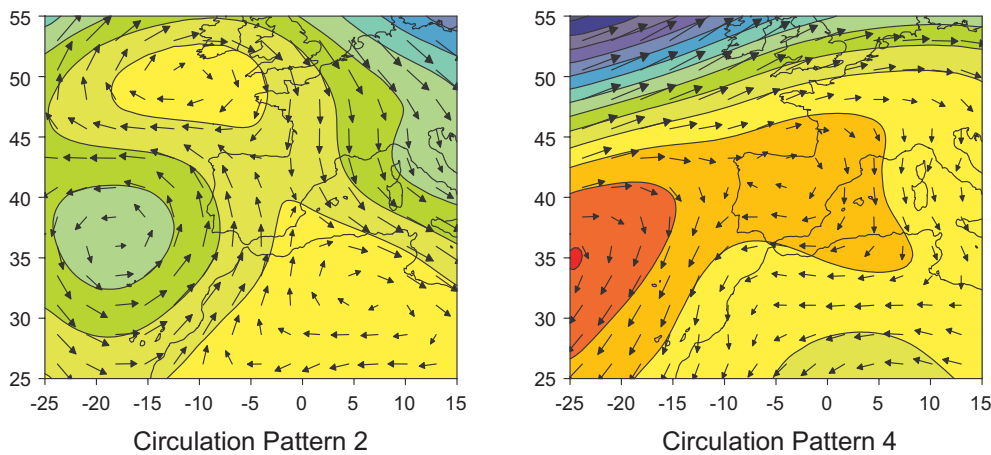


Figure 5.51: 850 hPa heights and wind vector composites of the two most active circulation patterns in terms of fire weather risk along northwestern Spain.

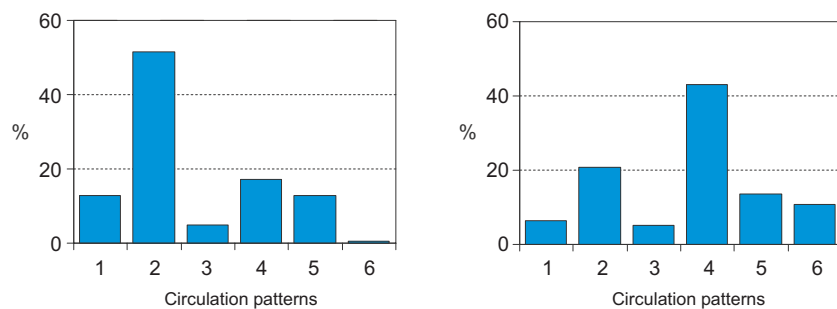


Figure 5.52: Number of high risk days by region (left, coastal Galicia; right Meseta).

5.4.1.4 Conclusions and recommendations

Synoptic climatology has been proven a suitable tool to relate the spatial and temporal patterns of fire weather risk over the Iberian Peninsula to the atmospheric circulation. The spatial patterns of low troposphere anomalies of temperature and relative humidity, as well as surface winds and geographical patterns of FWI index are consistent with the general configuration of the detected circulation patterns at 850 hPa.

In coastal Galicia, the onset and spread of the forest fires is linked to atmospheric circulation patterns (large-scale blocking) which trigger high-risk weather conditions (easterly and southeasterly flows) promoting a severe warming and drying. Extreme fire seasons occur when conditions are much drier than normal, capable to enhance the fuel flammability of a humid environment. The abundance of “industrial plantations” (Eucalyptus, Pinus) helps the fire to propagate rapidly, because of their flammability. In León and Zamora provinces (northern Meseta) a “structural” high risk conditions exists because of the warm and dry summer. Thus it is not required to have extreme weather conditions to initiate a large forest fire in this area. Most of the forest fires, affecting shrub vegetation, tend to occur after relatively wet winters. Such conditions support the growth of fine fuels that quickly dry out during the summer season.

However, neither the occurrence of high risk values nor specific circulation patterns during the summer season is, on its own, enough to predict the actual occurrence of very large fires. This apparent paradox responds to the complexity of the relationship

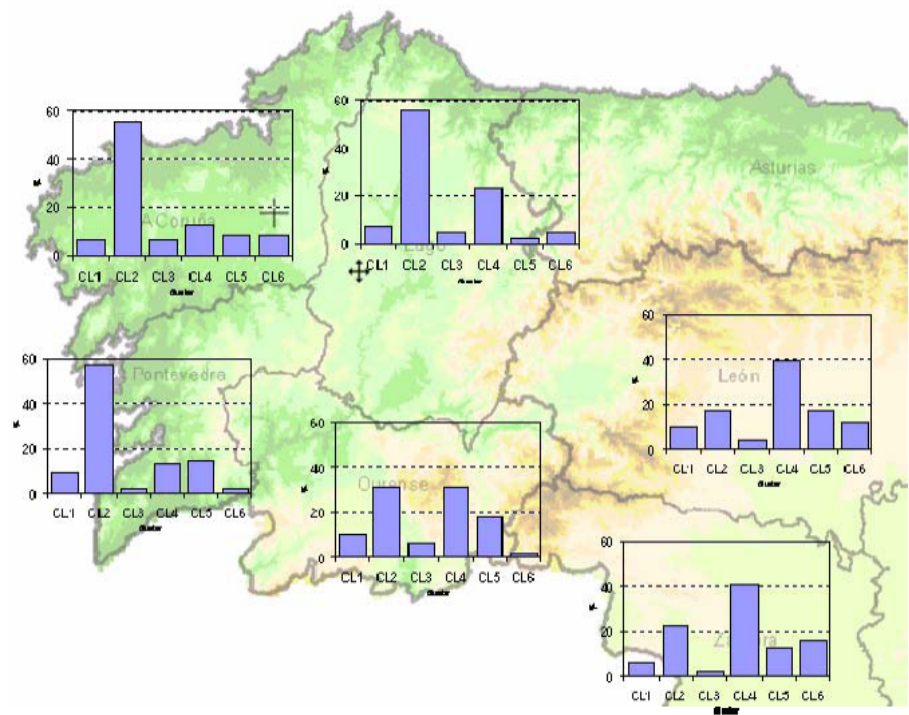


Figure 5.53: Occurrence of large forest fires (> 500 has) by circulation pattern and province.

between fire occurrence, weather and climate, and emphasises the obligation to consider additional factors. Very large wildfires use to cluster during catastrophic episodes of generalized burning, which cannot be explained solely by the occurrence of extremely dangerous day-to-day weather conditions. Long dry periods build on a very suitable background (high rates of fuel production and very flammable live and dead fuels at the beginning of the fire season), causing the spread of the initial focuses. Moreover, local weather conditions can activate destructive fire storms, characterized by high rates of flame spread, driven by extremely strong gusty winds. The results emphasise the obligation to combine both short term and long term climate variability to explain the occurrence of episodes of very large wildfires.

5.4.2 Links between forest fires and CTs in Portugal

Authors: Ricardo Trigo and Mario G. Pereira

5.4.2.1 Introduction

Atmospheric circulation classifications are important to study the role of weather in wildfire occurrence in Portugal because the daily synoptic variability is the most important driver of local weather conditions (PEREIRA et al., 2005). In particular, the objective classification scheme developed by Trigo and DaCamara (TRIGO and DACAMARA, 2000) to classify the atmospheric circulation affecting Portugal have proved to be useful in discriminating the occurrence and development of wildfires as well as the distribution over Portugal of surface climatic variables with impact in wildfire activity such as maximum and minimum temperature and precipitation.

Here, our aim is to test various existing algorithms for the classification of circulation patterns over Iberia, based on the COST733CLASS software developed by PHILIPP et al. (2010). This European project aims to provide a wide range of atmospheric circulation classifications for Europe and sub-regions (<http://cost733.met.no/>) with an ambitious objective of assessing, comparing and classifying all relevant weather situations in Europe (PHILIPP et al., 2010). In particular this case study aims to briefly describe the capacity of the different developed circulation classification schemes in discriminating wildfires and relevant meteorological variables.

5.4.2.2 Data and Methods

The data used to perform this study includes:

- The Portuguese wildfire dataset that includes information for each fire occurred in Continental Portugal during the 1980–2007 period (circa 500.000 events). The data was provided by National Forestry Authority (Autoridade Florestal Nacional, AFN);
- The ECA's meteorological dataset comprises series of daily minimum, maximum and daily mean temperature and daily precipitation amounts observed at meteorological stations in four Portuguese weather stations (KLEIN TANK et al., 2002).
- The COST733 catalogues for the D09 subregion. We use different circulation type classifications (CTCs) developed using data from ERA40. For comparison purposes only CTCs with 9 classes and based on SLP (Tab. 5.17) were selected.

5.4.2.3 Results and discussion

Wildfires in Portugal are overwhelmingly concentrated during the summer season. The magnitude of a summer fire season results from the combination of favourable climatic preconditions (e.g. wet winter, dry and hot spring) with appropriate extreme summer weather (particularly the occurrence of heat waves and no precipitation (PEREIRA et al., 2005)). Therefore, any good CT classification method should be efficient in discriminating high values of maximum and minimum temperatures as well as the occurrence (or not) of daily precipitation.

Table 5.17: The 10 selected methods (relative to domain D9) and the variable used.

<i>WTC</i>	<i>Method</i>	<i>Variable used</i>
CKMEANSC09	k-means	SLP
ESLPC09	spatial similarity index of daily maps	SLP
KHC09	spatial correlation of daily maps	SLP
LITADVE	direction of advection, cyclonicity	SLP
LUNDC09	correlation-based	SLP
NNWC09	artificial neural networks	SLP
PCACAC09	S-mode PCA, k-means	SLP
PETISCO09	correlation-based S	SLP
SANDRAC09	simulated annealing	SLP
WLKC09	direction of advection, cyclonicity	U700, V700, Z925 and Z500

The percentage of summer precipitation associated to each class for Domain 9 during fire days is represented in Fig. 5.54 (left). It is striking that some classifications (e.g. WLKC09) are better discriminating in just a few classes those rainy days. On the contrary, other classification algorithms do not reveal such capacity (e.g. NNWC09). Naturally, one must bear in mind that the frequency of each class is not uniform, and varies a lot between different classification methods (Fig. 5.54, right). An analysis was performed for both maximum and minimum temperature and results summarized in graphics such as those presented in Fig. 5.55 (Tmax, left). Once again some of the classification schemes appear to discriminate better between terciles of Tmax values, particularly PCACAC09, SANDRAC09, PETISCO09 algorithms.

Finally we have applied the same methods to both number of summer fires and total burned area and summarized some of the results in a similar way (Fig. 5.55, right). Some classes assume a fundamental role in terms of the frequency of incidence. This is particularly evident for the CKMEANS, LUNDC09, PCACAC09, SANDRAC09, PETISCO09 and WLKC09. For example, three classes of CKMEANS, PCACAC09, SANDRAC09 and WLKC09 accounts for about 90% of total burnt area. It is also important to note the existence of classes with very high values of number of fires and burnt area per day.

The plot for the number of fires and burnt area patterns are quite similar, concentrating significant high values in just a few classes which confirm the ability of those particular CTCs to study the fire weather regime, in Portugal.

5.4.2.4 Conclusions

Following on previous analysis it is possible to conclude that the vast majority of burned area in Portugal is associated with a relatively small number of weather types, independently of the classification adopted. Nevertheless, results obtained here show that the CKMEANS, PCACAC09, SANDRAC09 and WLKC09 algorithms are better discriminating patterns associated to wildfires in Portugal. Moreover we show that this capacity to discriminate is also related to the ability of some classifications to discriminate meteorological variables that control fire on a daily basis, namely precipitation and Tmax.

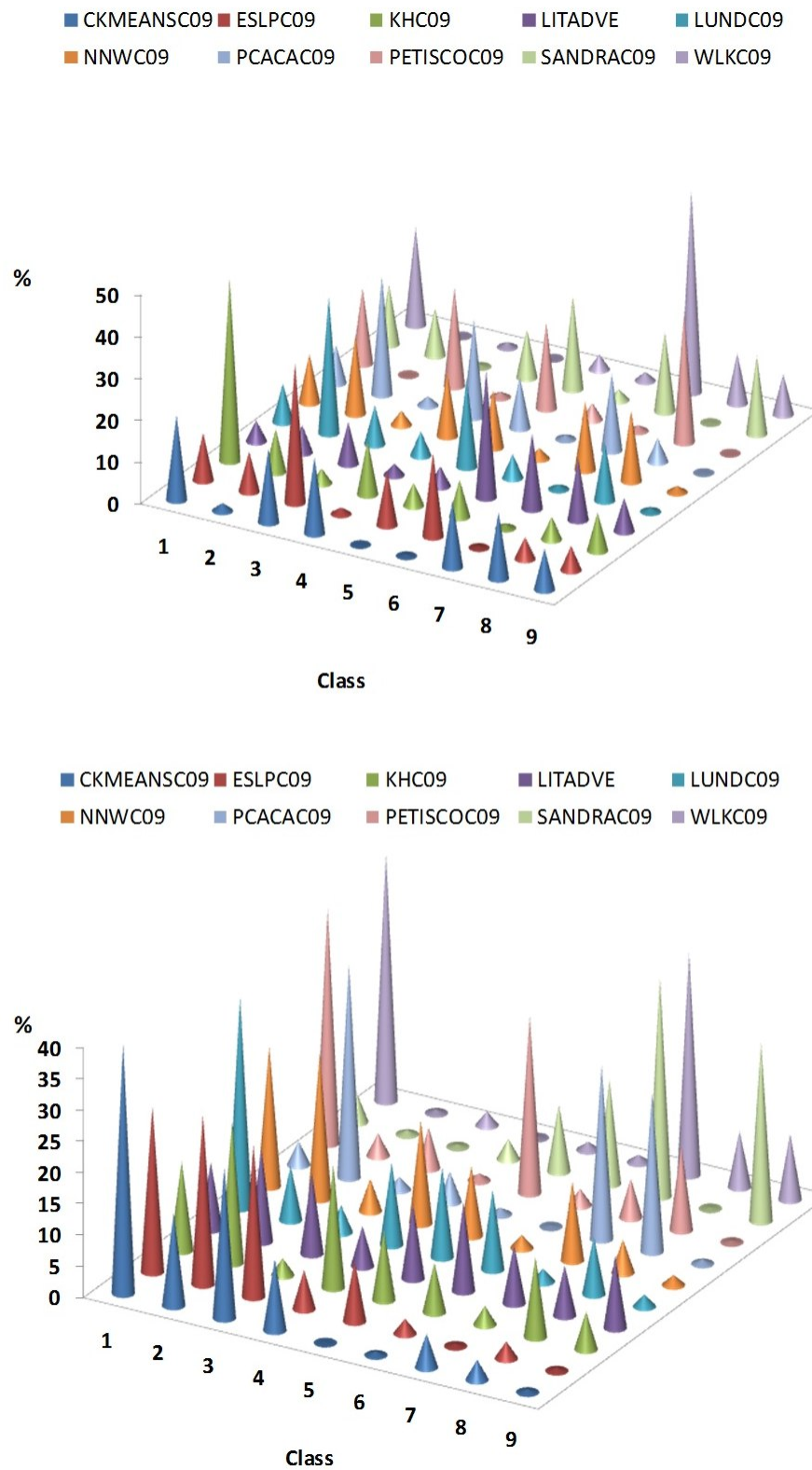


Figure 5.54: Occurrence of large forest fires (> 500 has) by circulation pattern and province.

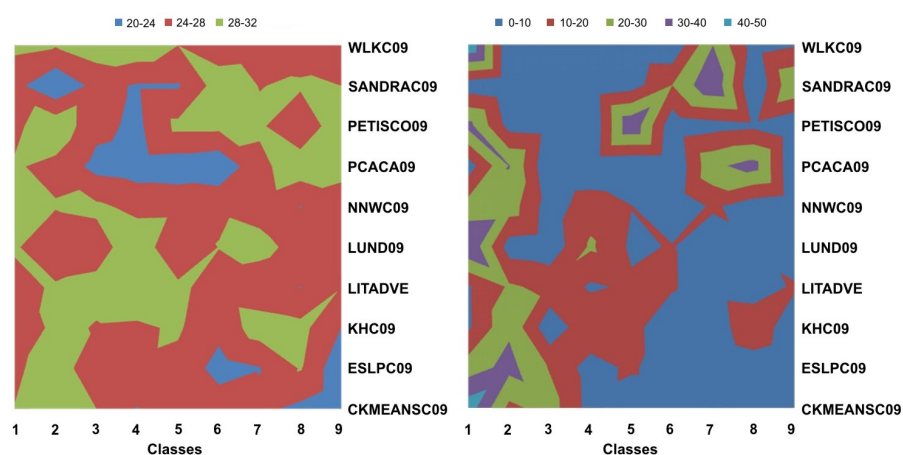


Figure 5.55: Range of maximum temperature in summer associated to each class used by the 10 different classification methods (left). Percentage of total number of fire days associated to each class used by the 10 different classification methods (right).

5.4.2.5 Recommendations

- **Family of algorithms**

In general it seems that CKMEANS, PCACAC09, SANDRAC09 and WLKC09 algorithms are better discriminating patterns associated to wildfires in Portugal.

- **Domain size and locations**

Only classifications related to Domain 9 were used. Not appropriate to use of a larger domain.

- **Number of classes**

We have used 9 classes of CTs consistently. Previous works with summer wildfires suggest that a relatively small number of classes should be taken into account (unlike studies developed for winter).

- **Input variables**

The use of multiple input variables considered in WLKC09 appears to perform very well. Further combinations are not tested for this study, but intuitively it should be better to use several variables instead of only SLP as input variable.

- **Seasonal**

Doesn't make much sense because the vast majority of fires (90%) in Portugal occur in summer.

5.4.3 Synoptic control on wild fires in Greece

Author: Pavlos Kassomenos

5.4.3.1 Introduction

Climatic/Meteorological factors are similarly important to the ignition and spread of wild fire occurrences. The area burnt depends on the location, land fragmentation, season, latitude, topography, fuel characteristics, in association with contingency factors including anthropogenic fire suppression and site accessibility. Meteorological conditions at the time of wildfires have been investigated in much greater detail than the way these fires relate to the larger scale atmospheric conditions during the previous days or months. Seasonal climatology displays a significant influence on fire occurrence, and it has been suggested that longer period climatic, variations have been shown to override meteorological and environmental influences of a shorter temporal length. There are several synoptic classification schemes that can be used for a wide area as a tool for linking wild fires and prevailing weather systems.

Greece covers an area of 130.875 km² with approximately 50% characterised as forest and 80% as mountainous. Specifically, according to the Greek National Forest Inventory, forests cover 6.513.068 ha. Greece has experienced intense forest fires with an increasing frequency since the early 1970s. Recently, there are some efforts aiming at studying forest fires in Greece, especially in the context of fire management (BONAZOUNTAS *et al.*, 2005). The objective of this study is to investigate the possibility of using synoptic classification schemes to obtain information on the occurrence and extent of wild fire events that occurred in Greece during the years 1985–2004. Wildfire climatology research is in its infancy and the proposed work has not been undertaken previously in Greece.

5.4.3.2 Data and Methodology

Forest fire data (wild fires burnt area higher than 200 ha) for the period 1985–2004 (April 1–October 30) was extracted from the statistical archives of the National Forest Inventory and the Fire Service in Greece. The algorithms SANDRAS, KHC, LUND, KMEANS, DKMEANS and HCL (Hierarchical Clustering with Ward's minimum variance method) of the catalogue COST733 v1.2 defined over Domain 10 (34–49°N and 7–30°E) with three, seven and fifteen day sequences were used. The classifications with statistically significant results above applied the methodology introduced for flood occurrence by DUCKSTEIN *et al.* (1993) to forest fire events.

5.4.3.3 Results and Discussion

Three Days Sequences

For classifications with 9 classes, HCL classes 1–3 occurred for 79% of the days analysed but during these 3 synoptic types 89% of the days with wild fires were observed, (henceforth denoted as 79%/89%) showing that days with wild fires were a little more frequent than the appearance of the certain synoptic types during the fire season of the 20-y period analysed. The same was found for synoptic types 1 and 2 for SANDRAS, DKMEANS and KMEANS algorithms (52%/65%). On the other hand for LUND and KHC algorithms, wildfires are more or less dispersed among the categories. Specifically

the three most frequent categories of these catalogues correspond to 48% of the days (synoptic types 1, 2 and 5) for LUND and 44% (1, 2 and 7) for KHC and are associated with 60% and 56% of the wild fire events respectively. During the three most frequent synoptic types of KMEANS, 78% of the total burnt area was lost. The corresponding percentage for HCL was about 86%.

It is important to describe the surface atmospheric pressure regimes during the prevailing synoptic classes. For KMEANS, class 1 is associated with 43% of the days with wild fires events. During this class the surface atmospheric pressure over Greece is low for the first day of the sequence, while during the next two days the pressure becomes higher and high pressure systems are intensified over northern Italy and Northern Balkans. This combination intensifies the winds over Aegean Sea. Class 2, representing 22% of the days with wild fires events, is associated with anticyclonic conditions over Greece during the first day of the sequence, weakening the second day, while during the third day over the entire Greek territory, except Peloponnese and the South Aegean, the atmospheric pressure drops. During the days classified as class 3 (12% of the days with wild fires) the pressure over Greece is high during the first day of the sequence and a fast reduction of atmospheric pressure over Greece and the Aegean is observed till the third day.

For classifications with 18 classes, three synoptic types (1–3) of HCL occurred for 46% days/55% days with wild fires, followed by SANDRAS (1–3), KMEANS (1–3) and DKMEANS (about 50%/67%). On the other hand the three more common categories of LUND (1, 4, 7) and KHC (1–3) catalogues represent a smaller fraction of the wild fire events (33%/41%). During the three most frequent synoptic types of KMEANS, 77% of the total burnt area was lost. The corresponding percentage for HCL was about 61%.

For Class 1 of the KMEANS catalogue the Greek territory is under the influence of a weak low pressure system during the first day of the sequence which gets deeper during the second and third day of the sequence. The second and third classes present almost similar behaviour with low pressure systems over Greece weakening during the second and third day of the sequence. The only difference of the two classes is the position of the high pressure system which lies to the northern Balkans in the second, and west/southwest of Greece, over the central Mediterranean in the third class. Classifications with 27 cases were tested but did not improve the prognostic ability of the fires and so not presented here.

Seven Days Sequences

For classifications with 9 classes, KMEANS's three most frequent synoptic types (1–3), occurred for 67% days/81% days with wild fire events during the period 1985–2004, followed by the HCL (1–3) (68%/75%). LUND sequential presents a dispersion among the categories (synoptic types 2, 4 and 5 are associated with 58%/44% of the days/days with wild fires. Attempts with the KHC and SANDRAS catalogues did not converge. During the three most frequent synoptic types of KMEANS, 84% of the total burnt area was lost. The corresponding percentages for DKMEANS and HCL were about 73%. Classes 1 and 2 for the KMEANS show that the surface atmospheric pressure over the Greek territory is low for all the days of the sequence presenting a strengthening of the low system from the first to the seventh day of the sequence especially over Aegean and the Eastern Greece. The only difference of the two classes is that the anticyclonic systems are located, in the first class, to the west of Greece, and in the second class

to the north. On the contrary the third class is associated with high pressure systems for the first four days of the sequence while for the rest three days an abrupt change to low pressure is observed. The surface atmospheric pressure is higher north and west of Greece for the first three days of the sequence.

For classifications with 18 classes, KMEANS and HCL present almost similar results, with three synoptic types (1–3 for all the catalogues) occurred for 51% of the days and are associated with 65–59% of the wild fires events. As in the 9 classes option LUND catalogue presents larger dispersion of the days with forest fire among the categories (synoptic types 3 and 6, summing up to 15%/30%). SANDRAS and KHC did not converge. During the three most frequent synoptic types of KMEANS, 70% of the total burnt area was lost. The corresponding percentage for HCL was about 52%.

Regarding total burnt area, KMEANS 1–3 synoptic types were associated with almost 70% of the total burnt area, while the respective figures for HCL and DKMEANS were 52–57%. For KMEANS the surface pressure regime shows the following: Class 1 (21%/27%) is characterised by a gradual prevalence of a low pressure system, which strengthens over the Greek territory from the first to the seventh day of the sequence. On the contrary Class 2 (16%/22%) is characterised by an increase of the atmospheric pressure at the surface from the first to the seventh day. The low pressure system initially established over the Greek territory is gradually replaced by a high pressure system. Class 3 (14%/16%) presents the same behaviour as Class 2 but the high pressure system is located north of Greece while in Class 2 it is located west of Greece. When the hierarchical clustering procedure is used, class 2 (23%/32%) is characterised by low pressure over the Greek territory while west of Greece, there is a high pressure system. The atmospheric systems are quite stable during all the days of the sequence. We do not present 15-d sequence due to the lack of space.

Statistical evaluation

For three days sequence/9 classes wild fires events occur more often than usual during Classes 1–2 of the KMEANS, DKMEANS, SANDRAS and HCL catalogues, while for classes 5 and 9, fires occur less often [Fig. 5.56(a)]. In the case of 18 classes, wild fires occur more often under classes 1–3 for the above mentioned catalogues, while under the rest classes, fires are less often [Fig. 5.56(b)]. For seven days sequence/9 classes wild fires events occur more often during KMEANS class 1, DKMEANS and HCL (classes 1–2), while under the rest of the cases they occur less often [Fig. 5.56(c)]. For 18 classes, KMEANS classes 1–3 present a more often than usual occurrence of fires, as is the case with DKMEANS classes 1, and 8–11, and with HCL classes 1, 2 and 4 [Fig. 5.56(d)]. The results also showed that for some synoptic types wild fires occur significantly more seldom than expected. As an example in 3 days–18 classes, classes from 9–18 occur more seldom than expected [Figs. 5.56(a)–(d)].

Anticyclonic conditions associated with high temperatures, low humidity and moderate winds are also responsible for the onset and the persistence of a wild fire. This work showed, that the hypothesis of using synoptic classifications to study and possibly predict wild fires events, in a way similar to air pollution episodes and mortality levels, is justifiable since both the frequency of occurrence and the extent of an event is statistically diversified among the synoptic types of a number of classification schemes.

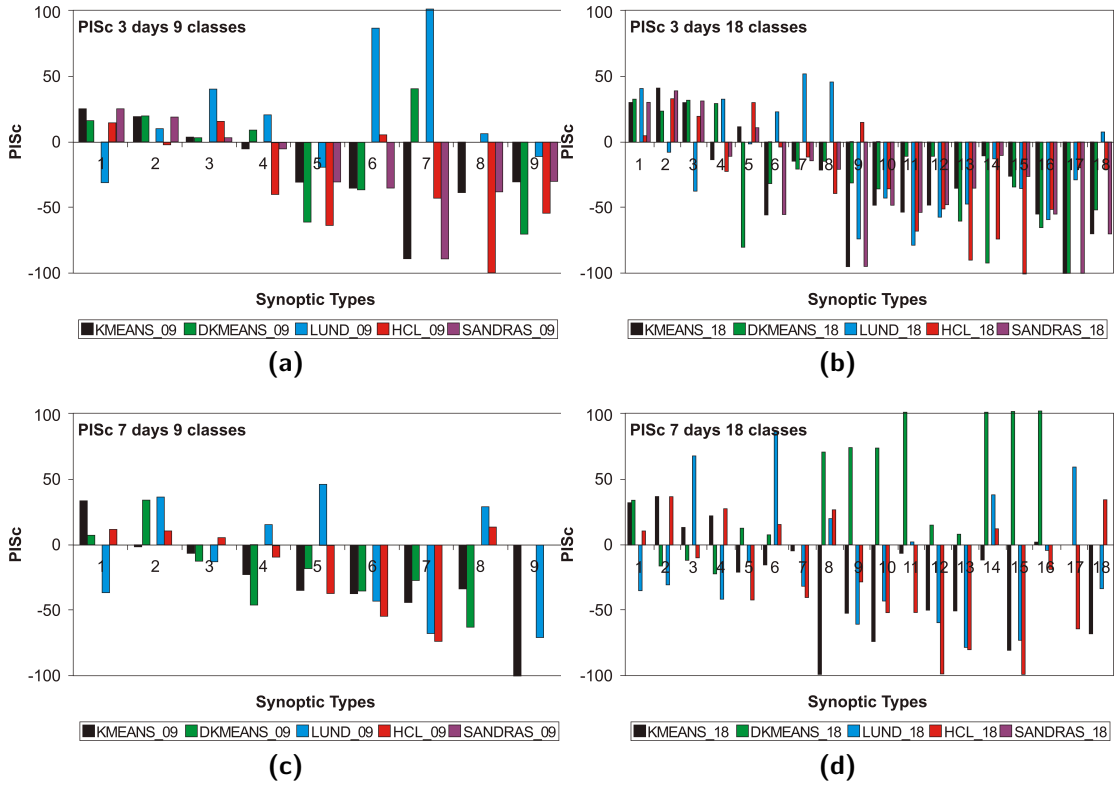


Figure 5.56: $PISc$ values of synoptic types. Selected catalogues with 3 and 7 day sequences.

5.4.3.4 Conclusions

Results showed that for hierarchical (HCL) and k-means algorithms (SANDRAS, KMEANS and DKMEANS), 67–89% of the wild fires events are associated with two or three synoptic types over Greece. The occurrence of the various classes is significantly different between the no-fire and fire-recorded groups for the 3 and 7 days sequences, while for 15 days sequence the differences are not statistically significant for almost all the cases. Using the burnt area as a criterion for the discrimination between synoptic catalogues, KMEANS, DKMEANS, HCL and SANDRAS (3 days, 9 and 18 classes) as well as KMEANS and DKMEANS (7 days, 9 classes) seem able to provide useful information on the possible extent of a wild fire event. Comparing 9 and 18 classes, the latter obviously presents more detailed information about the synoptic conditions but the 9 classes' case fulfills the argument of simplicity and it could be easier to be managed by the authorities as a predictive tool. Hierarchical clustering using Ward's method (HCL) presents a very good performance just as is KMEANS, a method successfully applied in various climatological/environmental applications. On the other hand, forest fires are almost evenly dispersed among the categories of LUND and KHC catalogues. In the majority of the classifications, wild fire events occur when a low pressure system prevailing over the area intensifies and the pressure gradient increases in the Aegean Sea. A second synoptic type is associated with gradual replacement of the low pressure system by a high pressure system.

5.4.3.5 Recommendations

- **Family of algorithms**

Subjective algorithms (Hierarchical clustering using Ward's method (HCL)) seem to provide a very good performance. The optimization method KMEANS seem to follow.

- **Number of classes**

We tested three families of classes e.g. 9, 18 and 27 for the classifications used. The 9 classes family seems to present the better performance. Moreover it fulfills the argument of simplicity and it could be easier to be managed by the authorities as a predictive tool.

- **Sequencing**

Three sequences were tested, e.g. 3, 7 and 15 days. The occurrence of the various classes is significantly different between the no-fire and fire-recorded groups for the 3 and 7 days sequences, while for 15 days sequence the differences are not statistically significant for almost all the cases.

5.4.4 Conclusions and recommendations – subgroup “Forest fires”

Synoptic climatology has been shown to be a very suitable tool in relating spatial and temporal patterns of fire weather risk over large parts of southern Europe to the atmospheric circulation. For all cases, the vast majority of the burnt area can be associated with a small number (2 or 3) of circulation patterns. Moreover, it is shown that the latter have the capacity to discriminate meteorological variables that control wildfire on a daily basis, such as (low tropospheric) anomalies of temperature and relative humidity (or precipitation). Some more details on the results of other tested configurations can be found in Tab. 5.18.

However, it is important to mention that neither the occurrence of high risk values nor specific circulation patterns during the summer season is, on its own, enough to predict the actual occurrence of very large fires. This apparent paradox responds to the complexity of the relationship between fire occurrence, weather and climate, and emphasises the obligation to consider additional factors. Very large wildfires use to cluster during catastrophic episodes of generalized burning, which cannot be explained solely by the occurrence of extremely dangerous day-to-day weather conditions. For example, long dry periods build on a very suitable background (high rates of fuel production and very flammable live and dead fuels at the beginning of the fire season), causing the spread of the initial focuses.

Table 5.18: Summary of the results from the case studies in the subgroup “forest fires”. The symbols refer to: (1) – –/++: A lower/higher number of classes improve the results; (2) +/–: improvement/deterioration of the results; (3) ≈: no conclusive evidence for a significant impact and (4) blank: This criterion is not tested.

<i>Cat. version</i>	<i>Variable tested</i>	<i>Preferred</i>		<i>Addt'l.</i>		<i>Seasonal ?</i>	<i>Sequence ?</i>
		<i>algorithm (class)</i>	<i>domain (domain of interest)</i>	<i>nr. of classes</i>	<i>input variable</i>		
1.2	Forest fires	OPT, PCA	small	– –	+	–	
1.2	Forest fires			– –			+

5.5 Other applications

As known, many environmental variables depend on the weather and climate. Often, these connections are non-linear and influenced by a combination of several different meteorological factors. The circulation types may be viewed as relatively simple tools that integrate many meteorological factors, as well as their combinations. Thus, circulation types are an ideal tool for studying the connections between different environmental variables and the climate. In addition to research on the direct “circulation-environment” connections, the circulation types are also good diagnostic tools for assessing which meteorological factors have the biggest effect on the environmental variable that is being studied. In that sense, the application opportunities for circulation classifications are practically endless.

Circulation types enable us to study the correlation between the environmental factors and the climate. Also, we can study which circulation conditions preceded the natural phenomenon that is being observed. For example, many extreme weather phenomena (e.g. drought), phenological phases or forest fires depend on the weather conditions that lasted a long period before the event. A similar approach can also be used to describe the main biometeorological characteristics of specific weather or circulation types considering typical geographical locations. Their seasonal variation is e.g. related with the seasonal pattern of asthma and acute respiratory infections or with the daily occurrence of diseases (e.g. [ESTELA, 1998](#)). Hence, circulation types give a generalized picture of the large-scale circulation or more local scale weather conditions characteristic of a natural phenomenon. This enables us to assess the circulation situations during which, for example, the birds or pests migrate; a forest fire or high ozone concentration spreads, etc. The main objectives of the “Other applications” subgroup of WG4 include:

- Stable isotopic signature of precipitation under various synoptic classifications (Subsection [5.5.1](#)).
- A regime dependent evaluation of the COSMO model over Germany ([5.5.2](#)).
- Objective optimization of the NWP forecast in Austria based on circulation patterns ([5.5.3](#)).
- Relating atmospheric circulation patterns to daily precipitation occurrence over the territory of Bulgaria using hidden Markov models ([5.5.4](#)).
- Connections between Circulation Type Incidence and the Modelled Potato Crop Yield in Estonia ([5.5.5](#)).
- Storminess and coastal erosion in Spain ([5.5.6](#)).
- Climate change analysis for the Carpathian basin ([5.5.7](#)).

It is important here to stress that the members of this subgroup can not provide a complete overview of the variety of potential applications. For other applications of circulation patterns, please refer to Section 4 of [HUTH et al. \(2008\)](#).

5.5.1 Stable isotopic signature of precipitation under various synoptic classifications

Author: Spyridon Lykoudis

5.5.1.1 Introduction

The stable isotopic composition of precipitation varies both spatially and temporal as a result of the selective removal of water molecules according to their weight, the so-called isotopic fractionation, which occurs during the evaporation of seawater and condensation of the advected water vapour (DANSGAARD, 1964). The isotopic composition of precipitation collected at a station depends on regional scale processes, like the trajectories of the precipitating air masses and their rainout history, as well as regional-, meso- and local-scale processes, such as local circulations and current weather conditions. The final isotopic signature of a precipitation event is conditioned by temperature in particular (GOURCY et al., 2005). Many of the controlling factors are correlated and depend to a large extent upon the synoptic circulation patterns and the associated weather types prevailing over the area. Many researchers have investigated this relationship between the isotopic composition of precipitation over an area, and the prevailing synoptic circulation patterns (e.g. RINDSBERGER et al., 1990; CELLE-JEANTON et al., 2001; IAEA, 2005).

Precipitation in Greece and the surrounding area results from air masses originating either from the Atlantic or from the Mediterranean and the isotopic signature of precipitation varies significantly depending on the origin of the water vapour and the trajectory of the air mass (RINDSBERGER et al., 1990; CELLE-JEANTON et al., 2001; LIOTTA et al., 2008). The aim of this study is to investigate whether synoptic circulation patterns can be used to obtain clearly identifiable isotopic signatures for precipitation and, if this is possible, to investigate the relative performance of the various synoptic classification / weather typing schemes in terms of methodology and number of classes used. More information can be found in LYKOUDIS et al. (2010).

5.5.1.2 Data and methods

The isotopic data, namely $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values for precipitation events, were derived from the Global Network of Isotopes in Precipitation (GNIP) on-line archive (http://www-naweb.iaea.org/napc/ih/IHS_resources_gnip.html) and correspond to precipitation events collected at four stations: Pendeli-Athens (Greece), Rome (Italy), Kozina (Slovenia) and Villacher Alpe (Austria). The temporal extent of the isotopic dataset is limited but isotopic data of this kind are rather scarce worldwide. The classification catalogues COST733CAT v.1.2 with 9, 18 and 27 classes defined on Domain10 (34°N–49°N, 7°E–30°E) were used.

The classifications were tested for their ability to discriminate isotopic signatures using the non-parametric Kruskal-Wallis H-test (SPRENT, 1993), where the null hypothesis represents equality of distribution location. The test was applied to all eight isotopic data sets (4 cities with 2 isotopic values each) and all the catalogues included in COST733CAT v1.2. For the classifications with significant discrimination of isotopic signatures according to the Kruskal-Wallis test for at least 5 out of the 8 data sets, additional statistics were calculated: the Explained Variation (EV), the Pseudo-F statistic (PF) and

the Within-type Standard Deviation scaled by the respective mean (WSDS). For each isotopic station, scores were assigned to the classification schemes according to their performance in these criteria, for each isotopic parameter $\delta^{18}\text{O}$ and $\delta^2\text{H}$ separately, and then the scores were averaged to give a single score for each evaluation criterion. An overall ranking was obtained for each criterion by averaging the scores of the stations. The best five classifications for each criterion were selected to provide some insight in possible preferred classification schemes, algorithms, or even number of classes, in the context of stable isotopes – synoptic circulation relationship.

5.5.1.3 Results

The Kruskal-Wallis test was applied to the $\delta^{18}\text{O}$ and $\delta^2\text{H}$ data from each site separately. Cases with statistically significant H statistic (5% significance level) were flagged and the occurrence of each classification scheme among the flagged cases was counted. Classifications with total counts greater or equal to five were considered successful, as they provide statistically distinguishable isotopic signatures for the majority of the data sets. Overall, 17 classifications passed the test and are listed in Tab. 5.19.

Table 5.19: Classifications qualifying the separability criterion based on Kruskal-Wallis H test.

<i>Classification</i>	<i>Algorithm</i>	<i># of classes</i>	<i>Classification</i>	<i>Algorithm</i>	<i># of classes</i>
CKMEANSC09	Optimization	9	LUNDC09	Leader	9
ESLPC09	Leader	9	NNWC18	Optimization	18
EZ850C10	Leader	10	PCACA	Optimization	4
EZ850C20	Leader	20	SANDRA	Optimization	12
GWT	Threshold	18	SANDRAC09	Optimization	9
GWTC10	Threshold	10	SANDRAS	Optimization	30
GWTC18	Threshold	18	SANDRASC09	Optimization	9
LITC18	Threshold	18	SANDRASC18	Optimization	18
			TPCAC27	PCA	27

A sensitivity analysis was carried on the results of the Kruskal-Wallis test. Using data from only three months (October to December) reduced the number of statistically significant cases dramatically, while data from a single year, even though reduced the number of significant cases, lead to a similar number of valid classifications and with similar dispersion between optimization-PCA and leader-threshold types. Classifications with 12 classes or less, count for more than half of the selected algorithms. Seasonal variation of the stable isotopic composition of precipitation seems to provide enough variability to distinguish between classes, whereas a single season doesn't, and year-to-year variation is not as important.

The effect of any given synoptic type to the isotopic composition of the precipitation is likely to be different for each station. This is due to the differences in the precipitation and temperature regimes that each type represents, and to the spatial variability of these

regimes resulting in different conditions prevailing over each station. For instance, class 18 of SANDRAS classification does not occur during summer (JJA) and represents a trough extending over most of Italy and mainland Greece, with its axis along the Adriatic Sea (Fig. 5.57). This type corresponds to mid-low isotopic values for Kozina, middle values for Villacher Alpe, low values for Rome and high values for Pendeli. Pendeli is under a moderately warm, weak south-westerly to westerly flow that produces light or not at all precipitation, mainly during spring or autumn. Under these conditions the precipitated water is expected to be rather enriched in heavy isotopes. Rome on the other hand is under a westerly to north-westerly flow with warm temperatures and no rain during winter, but cooler temperatures and precipitation especially during spring. Intense showers under cool temperatures are likely to be depleted in heavy isotopes. Finally, Kozina and Villacher Alpe are in the center of the trough receiving significant amounts of precipitation throughout the whole period from autumn to spring. Furthermore while during the transient seasons the temperature at these stations is cool to cold, during winter it is rather warm, favouring precipitation in the form of rain rather than snow. An aggregate rain sample would have the observed ‘average’ isotopic composition.

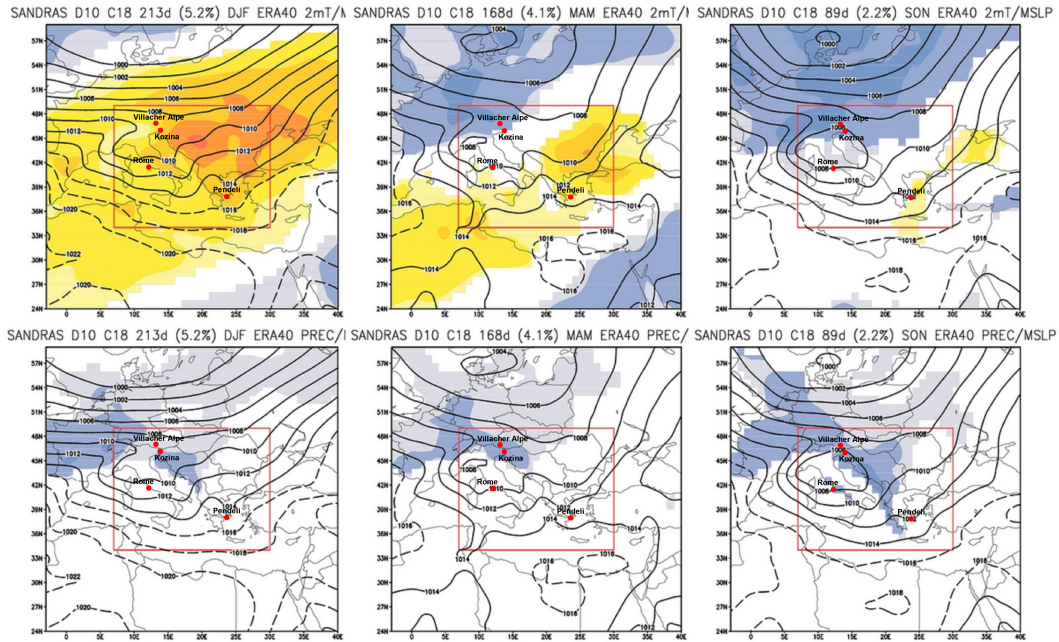


Figure 5.57: Spatial patterns of 2m air temperature, precipitation and MSLP for class 18 of SANDRAS catalog. Graphs adapted from cost733.geo.uni-augsburg.de/cost733cat-1.2/plot.html.

In order to investigate the ability of the selected classifications to represent the observed variability of the stable isotopic composition of precipitation events, for each one of the 17 selected classification schemes, isotopic parameter and site, we calculated three evaluation criteria, namely EV, PF and WSDS. The classification schemes were ranked according to these criteria.

Classifications with many classes (SANDRAS, TPCAC27, EZ850C20 and SANDRAC18) are best performing for all sites according to EV, while PCACA with 4 classes is amongst the worse two performing classifications for all tests except one (Pendeli $\delta^2\text{H}$). According to EV, a better representation of the observed variance is achieved with a large

number of classes, but results from Pseudo-F statistic and WSDS seem to be less sensitive to the number of the classes. The site Kozina shows the best overall performance (lowest within class variability) with the threshold classifications GWT and GWTC10 (18 and 10 classes respectively), and Rome $\delta^2\text{H}$ shows the worse with CKMEANSC09 and SANDRA (9 and 12 classes respectively).

Classifications based on optimization algorithms are the most frequently found among the 5 highest ranking for each one of the three evaluation criteria, as suggested by the results from the Kruskal-Wallis test where half of the selected classifications followed optimization algorithms. Leader algorithms also perform overall as expected from Kruskal-Wallis, while threshold methods are found less performing than PCA methods in the additional tests [Fig. 5.58(a)].

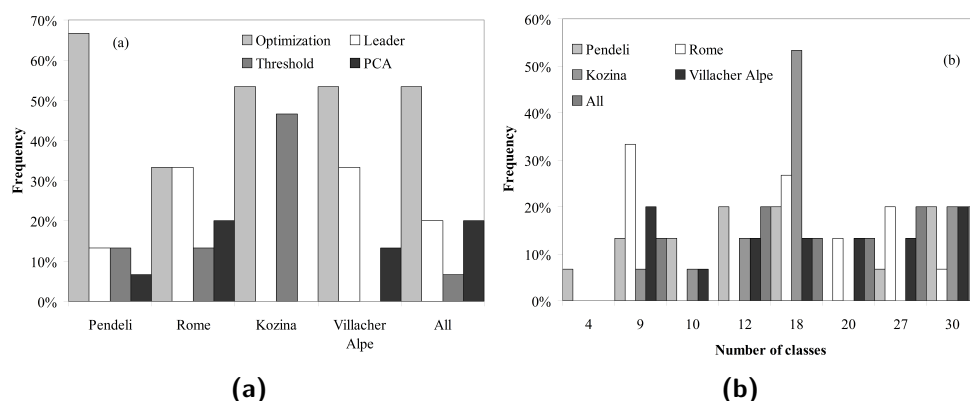


Figure 5.58: Frequency of participation in the top 15 classification schemes: a) classification algorithms, b) number of classes.

Classifications with 18 or more classes show overall better performance than those with 9–12 classes. The two classifications with more than 20 classes selected by Kruskal-Wallis (i.e. 11% of selected classifications) account for more than 26% of the ‘best performing’ classifications according to the additional tests [Fig. 5.58(b)]. This suggests that, even though a few classes may provide adequate aggregation and as a result good separation for most of the data, they do not represent well the observed variability. A high number of classes for specific classifications can reproduce finer distinctions leading to a better overall performance.

5.5.1.4 Conclusions

The analysis presented above has shown that it is possible to use a synoptic classification scheme to classify precipitation events into groups with clearly identifiable stable isotopic signatures, even though local meteorological factors may affect the coherence of these results when moving from one isotopic parameter to another. Classifications based on optimization and PCA algorithms perform better in all the tests applied herein. The number of classes has an effect of its own on the tests used: location separability is on average better when classifications with a small number of classes are used, yet the best separation is obtained by classifications with many classes obtained by optimization and PCA based algorithms, and the observed variance is also better captured when the classification has a larger number of classes. These results however informative should

be considered with caution as they are based on the limited dataset available at the time. Further investigation and a larger dataset are needed to obtain a consistent synoptic-based classification of the isotopic composition of precipitation events.

5.5.1.5 Recommendations

- **Family of algorithms**
Optimization algorithms seem to provide both better separation between isotopic signatures and an adequate description of the observed variation.
- **Number of classes**
18 or more classes seem to be better suited for this application. Fewer classes provide, on average, better separation but fail to describe the observed variation.
- **Sequencing**
Three of the 17 qualifying catalogues were produced by the only sequential classification in COST733CAT v1.2.

5.5.2 A regime dependent evaluation of the COSMO model over Germany

Authors: Tom Akkermans, Tim Böhme, Matthias Demuzere, Susanne Crewell, Christoph Selbach, Thorsten Reinhardt, Axel Seifert, Felix Ament and Nicole P.M Van Lipzig

5.5.2.1 Introduction

Model evaluation is a necessary part of model development. A general assessment of overall model biases is common among the numerical weather prediction and climate community who possess the standard tools for this evaluation. Nevertheless, actual model development often relies on case studies, which implies a choice for suitable cases (JAKOB, 2004). This calls for a different approach which identifies situations in which the model bias is higher than the average, here called problem regimes. The identification of regimes is nothing more than stratifying the evaluation dataset according to an external parameter (observed or modelled) which represents the differentiation in situations. The stratification of the verification dataset in relatively homogeneous sub-samples also allows for detection (unmasking) of systematic model biases (ROSSA et al., 2008). An example of regime dependent model evaluation was done by ROSSA et al. (2003) and ROSSA et al. (2004) for the Swiss Alps with the aLMo model. They stratified the dataset according to the Schüepp classification scheme, designed for the Alpine region including also 4 advective regimes (i.e. the main wind directions). One of the results was an overestimation of precipitation on the windward side of the Alps and a pronounced underestimation on the lee side (ROSSA et al., 2004).

The aim of this research is to apply a similar evaluation method. Regimes are firstly defined by geopotential height fields as external parameter, which reflect the large-scale atmospheric circulation. Eight directional and two vorticity regimes are distinguished and an average precipitation bias for each regime is calculated. Such a circulation regime can be interpreted as the large-scale geostrophic wind direction, and hence determines the wind- and leeward side of topographical features. This method is here illustrated for Germany with the modelled precipitation in COSMO, a non-hydrostatic limited-area model for numerical weather prediction (NWP). The model output is evaluated with an extensive dataset, formed in the General Observation Period (GOP). This project has been performed within the German Priority Program on Quantitative Precipitation Forecasting (PQP).

5.5.2.2 Data and methods

The classification method used in this study is the Jenkinson-Collison method (JENKINSON and COLLISON, 1977) that was optimized to 16 gridpoints by JONES et al. (1993). The difference with the original method as implemented in the COST733CLASS software “JTC” is that here, not sea level pressure but 850hPa geopotential height is classified based on the values from 16 grid points. The distance is adapted to the domain of interest and can be easily modified to other scales. Different from the above-mentioned studies, geopotential data in 850 hPa level are used in order to avoid surface influences. COSMO output fields are used to derive the circulation patterns.

Six-hourly accumulated precipitation (mm/6h) is derived from the operational COSMO model output, by averaging all available forecasts for the targeted accumulation period. All forecasts are taken into account because the overall model performance is investigated. The total precipitation is considered and hence includes solid precipitation. Observations are taken from the GOP dataset, which is discussed in-depth by [CREWELL et al. \(2008\)](#) and [MATHES et al. \(2008\)](#). The raingauge-only product (RANIE1) is an interpolated surface precipitation analysis by the German Meteorological Service (DWD) with 6h precipitation sums on a 1 km spatial resolution. Some quality checks are applied (e.g. outlier test) and orographic influence is taken into account by a regression method. Also a combined rain gauge-radar product is available (RANIE2) with the same specifications; however, these are not used to present results because of radar-specific artefacts. To make an evaluation possible, the RANIE product is converted to the COSMO-DE and COSMO-EU grid by means of an aggregation algorithm. RANIE observations are then subtracted from COSMO model output. This forms the evaluation-dataset with model biases (mm/6h) for each accumulation period in the years 2007 and 2008 (00–06UTC, 06–12UTC,...). A positive bias indicates model overestimation, a negative bias indicates underestimation.

5.5.2.3 Results

The COSMO-EU model strongly overestimates precipitation at windward sides and underestimates at lee sides (Fig. 5.59). The coarse COSMO-EU version of the model does not resolve convection, and hence has a convection parameterization scheme, the revised Tiedtke scheme ([TIEDTKE, 1989](#)). Obviously, the scheme triggers convection too often at the windward side of hills and low mountains, while observations indicate that convection is rather triggered on the ridges/crests of these topographic features ([CREWELL et al., 2008](#)). This “windward/leeward effect” is found in all mesoscale NWP and climate models which require convection parameterization, such as COSMOCH7, ALADIN, MM5, ETA ... ([WULFMEYER et al., 2008](#)). The bias results show the orographic influence. When looking to the bias composite of a particular regime, one can see that orography has the largest impact on the precipitation bias where the hill/mountain ridge is perpendicular to the wind direction, because of the larger area with forced flow uplift. The same conclusions can be drawn from the vorticity regimes (figures not shown). This effect can clearly be seen in the Thüringer Wald Gebirge (lower red square in Fig. 5.59), a mountain ridge which is oriented along a northwest-southeast direction. In the north-western circulation regime, the overestimation is relatively small in areal extent and can be found on the northwestern hillside, while in the western and southwestern regime the area of overestimation is much larger and extends over the entire (windward) mountain ridge. Another example is the Harz mountain, located north of the Thüringer Wald Gebirge and the most northern topographic feature with a significant impact on the bias (upper red square). Here one can compare the western and eastern circulation regime. For the absolute bias (not shown) the eastern circulation regime does not show any windward/leeward bias, but for the relative bias (Fig. 5.59) a purely orographic signal is visible with an overestimation on the eastern side. Note that areas with observed precipitation values lower than 0.20mm/6h are excluded. In some classes the orography-related biases are smaller (e.g. E, SE, S). This is due to a lower absolute rainfall amount (continental vs. maritime air masses) and a significant lower sample size which limits the probability that spatially fixed biases will overcast random events.

5.5.2.4 Conclusions

The results of the COSMO-EU analyses confirm known model deficiencies. In this paper, regime dependent model evaluation is used to analyse windward/lee related biases in a systematic way, isolating cases in which the large-scale circulation behaves in a similar way and hence avoiding mixed signals. The Western and Northwestern circulation regimes in which the effect plays a major role, count for about 40% of all cases, which indicates the relative importance of the findings.

5.5.2.5 Recommendations

It is not possible to provide any further recommendations, as only the Jenkinson-Collison scheme was tested here.

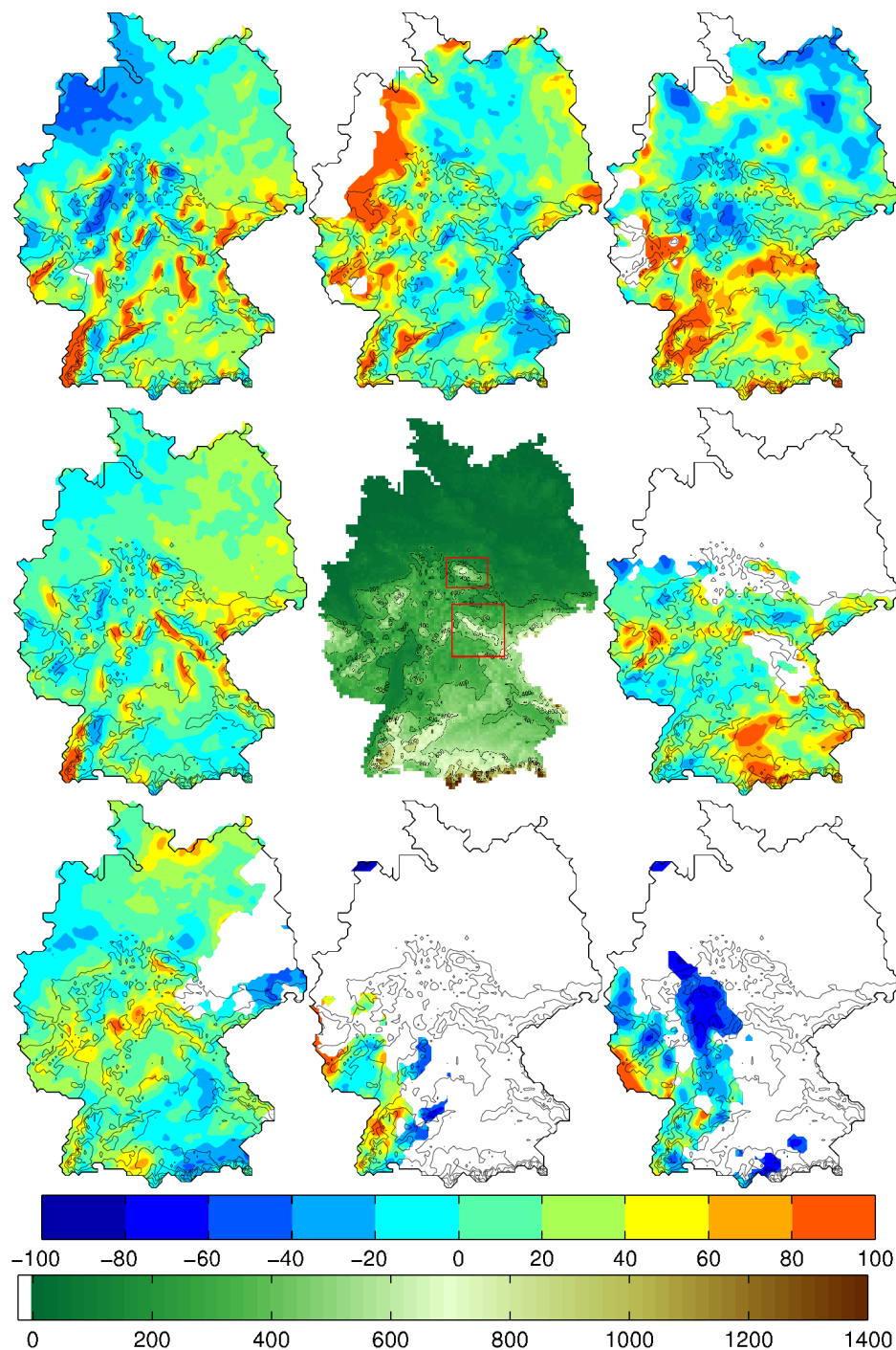


Figure 5.59: Relative differences (in %) between predicted and observed accumulated precipitation (mm/6h) in Germany for each directional circulation regime using the COSMO-EU model and RANIE rain gauge observations. CT's are Northwest, North, and Northeast (first row), West and East (second row), and Southwest, South, and Southeast (third row). A digital elevation model (m) at COSMO-EU resolution is given in the centre. Upper scale bar refers to the relative differences (in %), while the lower scale bar refers to the elevation (in m).

5.5.3 Objective optimization of the NWP forecast in Austria based on circulation patterns

Authors: Alexander Beck and Thomas Krennert

5.5.3.1 Introduction

In recent years both the quality and the number of operational weather forecasts and related products has increased substantially. Both meteorological forecasters and automatic forecasting systems have to deal with these growing data to deliver the most accurate and user-targeted forecast products. To assist the forecaster in dealing with the diversity of information available from different models an automated evaluation and guidance system, so-called ‘META’-forecast system, has been developed at ZAMG. The purpose of the system is twofold: First, to provide guidance for the operational forecaster through an objective evaluation of the model’s current performance. Second, to compute automated and optimized point forecasts by objectively combining different model forecasts.

5.5.3.2 Data and Methods

The ‘META’-forecast system operates since December 2008 for short-range forecasts up to 72-hours. The system is designed to incorporate direct model output (DMO) from different global (ECMWF, DWD, UKMO) and limited area models (ALADIN-Austria, COSMO-EU, UKMO-NAE) for user-targeted parameters such as minimum and maximum temperature, wind speed, global radiation and precipitation amounts for defined accumulation periods. Additionally, the system provides a weather symbol and thus can be used as a basis for automated point forecasts requiring a graphical representation (i.e., websites). For the current version of the system, the bias-corrected DMO data are combined using a mean absolute error based weighting-algorithm computed over a pre-specified number of previous forecasts (i.e., ten days). The weights are estimated individually for every station, parameter and forecast time. Additionally a weighting algorithm based on Bayesian model averaging (BMA) (RAFTERY *et al.*, 2005) has been evaluated. Careful treatment of model biases is essential for the successful application. Therefore a fairly complex bias correction algorithm is applied prior to the computation of the actual weights. It utilizes historical data over different periods (recent months, last week, current performance) to estimate the present biases of the individual models for all parameters and lead times.

5.5.3.3 Results

Compared to the bias-corrected DMO forecast the errors for point forecasts (in terms of MAE or RMSE) are thereby reduced. Hence, the error distribution is sharper reducing the number of bad forecasts substantially. As an example, Fig. 5.60 shows the performance of META in comparison to DMO and bias-corrected forecasts. The box-plots represent the distribution of the absolute errors in terms of temperature for 30 stations in Austria. As can be seen, the bias correction step has a substantial impact on the overall performance and thus is of crucial importance for the whole system. The number of outliers corresponding to the worst forecasts is substantially reduced in the

META-system (red crosses). Evaluations for other parameters or periods reveal similar results.

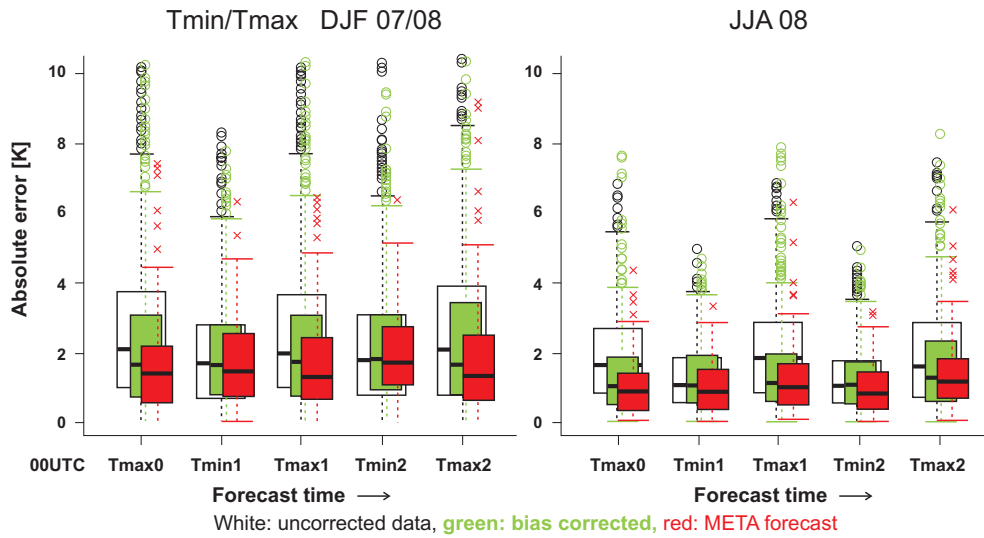


Figure 5.60: Evaluation of the performance of the META-system (red boxplots) compared to DMO (white), bias-corrected data (green) for temperature (30 stations in Austria).

Experience from a subjective evaluation with operational forecasters has shown further potential improvement of the system, if model performance is related to the current circulation pattern. Identifying the circulation pattern can be used both for estimating the biases and for computation of the actual weights. However, for the implementation a few restrictions have to be considered. First, ideally the temporal evolution of the circulation pattern should also be taken into account. Thus one would need to look for cases where both the analysis and the subsequent forecasts correspond to the present situation. This requires huge amounts of historical data (for all models!) and is thus not feasible for operational application. Second, the evolution and thus the behaviour of the individual models might differ substantially. As a first step, only one model run is used to identify the circulation pattern (i.e., the most recent run from the ECMWF model). Moreover, the selection of the historical cases used for the bias correction and the weight computation is based on the circulation pattern of the analysis only. An extended version of the META-forecast system has been developed utilizing the automated circulation pattern classification WLKC733, which is available at ZAMG (PHILIPP et al., 2010). The classification names four directions (NE, SE, Sw and NW), one undefined flow and the vorticity (cyclonicity) at 925 and 500 hPa, respectively [COST733CLASS – User guide].

Fig. 5.61 shows a comparison of the enhanced version to the operational system for a period in Spring 2009. The overall improvement is fairly small, but for individual cases related to abrupt changes in the weather regime, a substantial reduction of the forecast errors was observed (not shown).

5.5.3.4 Summary and Conclusions

The META-forecast system is able to provide reliable optimized point forecasts and is used operationally at ZAMG for various purposes. The performance of the system in

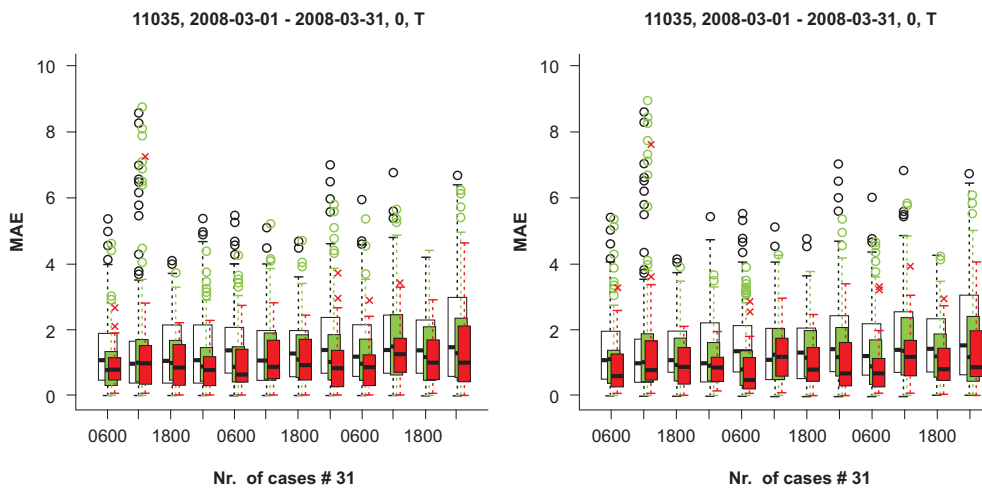


Figure 5.61: As Fig. 5.60, but comparing the operational version of the METAForecast system (left) to the enhanced version based on circulation patterns (right) for 2m temperature (March/April 2009; 30 stations in Austria).

comparison to the individual models is monitored continuously and thus provides guidance to the forecasters in this respect. The circulation-pattern based system is currently running in a pre-operational mode. Due to constraints related to the restructuring of the local databases providing the historical forecasts, the operational implementation of the system has been postponed to late 2010. However, in view of the encouraging results obtained so far, operational implementation is highly anticipated.

5.5.3.5 Future and Plans

Research is currently being carried out to incorporate the point forecasts from the METAForecast system with the high-resolution nowcasting system INCA (Integrated Nowcasting through Comprehensive Analysis) (HAIDEN and PISTOTNIK, 2009). The basic idea is to use the point forecasts as a surrogate for future “observations” and subsequently compute INCA ‘analyses’ for future time steps. A prototype of this system has already been coded. However, it is very expensive in terms of computational resources and at the moment not yet suitable for operational application.

5.5.4 Relating atmospheric circulation patterns to daily precipitation occurrence over the territory of Bulgaria using hidden Markov models

Authors: Neyko Neykov, Plamen Neytchev, Walter Zucchini and Hristo Hristov

5.5.4.1 Introduction

Non-homogeneous hidden Markov Models (NHMMs) have found widespread application in meteorology and hydrology in Australia, North and South America in studies of climate variability or climate change, and in statistical downscaling of daily precipitation from observed and numerical climate model simulations (see ZUCCHINI and GUTTORP, 1991; HUGHES and GUTTORP, 1994; HUGHES et al., 1999; CHARLES et al., 1999; BELLONE et al., 2000; CHARLES et al., 2003, 2004; ROBERTSON et al., 2004, 2005; VRAC and NAVEAU, 2007; VRAC et al., 2007). However, the NHMM methodology has not yet been employed for similar purposes in Europe, apart from some studies done by NEYTCHIEV et al. (2006), NEYTCHIEV et al. (2008), NEYKOV et al. (2008) and ZUCCHINI et al. (2008). Since 2005 we have investigated the use of the NHMM to link synoptic-scale, atmospheric circulation variables to daily precipitation data at a network of rain gauge stations, via several hidden (unobserved) “weather” states or “spatial precipitation occurrence patterns”. The evolution of these states is modelled as a first-order Markov process with state-to-state transition probabilities conditioned on some indices of the atmospheric variables, hence the term non-homogeneous. The NHMM states are identified as precipitation patterns that result from the model fitting procedure, while the role of synoptic atmospheric information is to influence the state transitions. This is in contrast with the traditional weather state models where each day is classified a priori into a state, according to synoptic patterns and precipitation does not affect the state definition. Due to these NHMM states the spatial precipitation dependence can be partially or completely captured.

5.5.4.2 Data

The NHMMs were fitted and independently tested to daily precipitation at 32 rain gauge stations covering broadly the territory of Bulgaria to synoptic atmospheric data. At each site a 40-year record (1960–2000) of daily October through March precipitation amounts is modelled. The cool seasons were considered only as the precipitation process in that period of the year is not influenced by convective phenomena. The days with precipitation amounts greater than 0.1mm were treated as wet days, the remaining days were considered as dry days. Each record value represents the precipitation total over a 24 hour period ending at 06 UTC. The atmospheric data consists of daily mean sea-level pressure, geopotential height at 500 hPa, air temperature at 850 hPa and relative humidity at 700 and 850 hPa on a $2.5^\circ \times 2.5^\circ$ grid based on NCEP-NCAR reanalysis dataset covering the Europe-Atlantic sector 30°W – 60°E , 20°N – 70°N for the same period.

5.5.4.3 Results

The first 30 years data were used for model fitting purposes while the remaining 10 years were used for model evaluation. Detailed model validation was carried out on various

aspects. Relating rainfall characteristics to atmospheric variables guarantees that the precipitation simulations are consistent with the observable atmospheric information. In this way NHMMs aid in understanding the probabilistic precipitation structure, see [ZUCCHINI et al. \(2008\)](#).

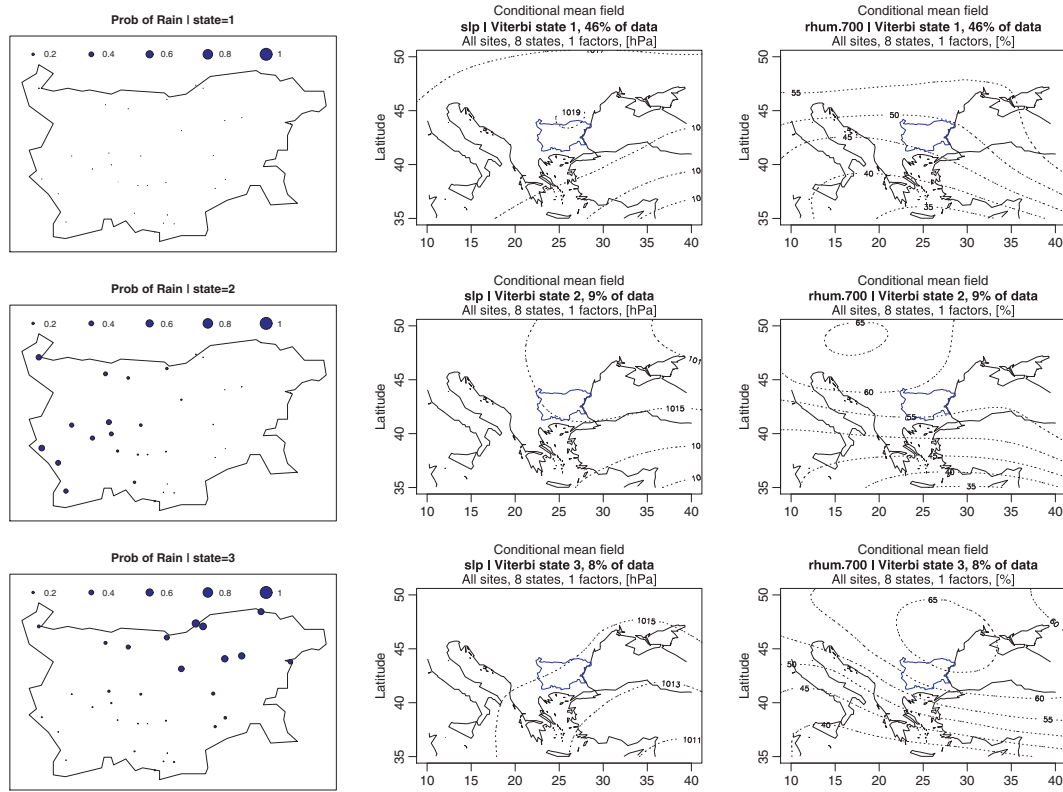


Figure 5.62: Precipitation occurrence patterns where the diameters of circles indicate daily precipitation occurrence probabilities at each site with the largest circle 1.0 (left column). Composite mean SLP (middle) and relative humidity at 700 hPa fields (right) averaged over all days classified under each state 1 to 3 (rows).

Figs. 5.62 and 5.63 illustrates the eight states obtained for the territory of Bulgaria. The precipitation states, 1st and 4th columns, are distinct and are representative of the synoptic conditions experienced by the territory of Bulgaria. The diameters of circles indicate daily precipitation occurrence probabilities at each site with the largest circle 1.0. About the mean SLP and relative humidity at 750 hPa patterns associated with the precipitation patterns we note that each day is first classified into its most likely state according to the Viterbi algorithm and, second, all days in a particular state are then averaged at each grid node for the atmospheric variables to obtain the corresponding composite fields. The states 1 and 8 are characterized by a low and high precipitation probability at all sites (47% and 8% respectively). The dry state 1 can be associated with an anticyclone over the Balkan Peninsula according to the MSLP fields presented at the 2nd and 5th columns. The remaining states exhibit regional features variation of the precipitation probability and can be characterized by lower mean sea level pressure values whereas the relative humidity values at 850 (not presented) and 700 hPa levels are higher than 65% and 55%, respectively. The weather pattern related with state 2 can be associated with Mediterranean cyclones centred over Northern Italy moving to Hungary

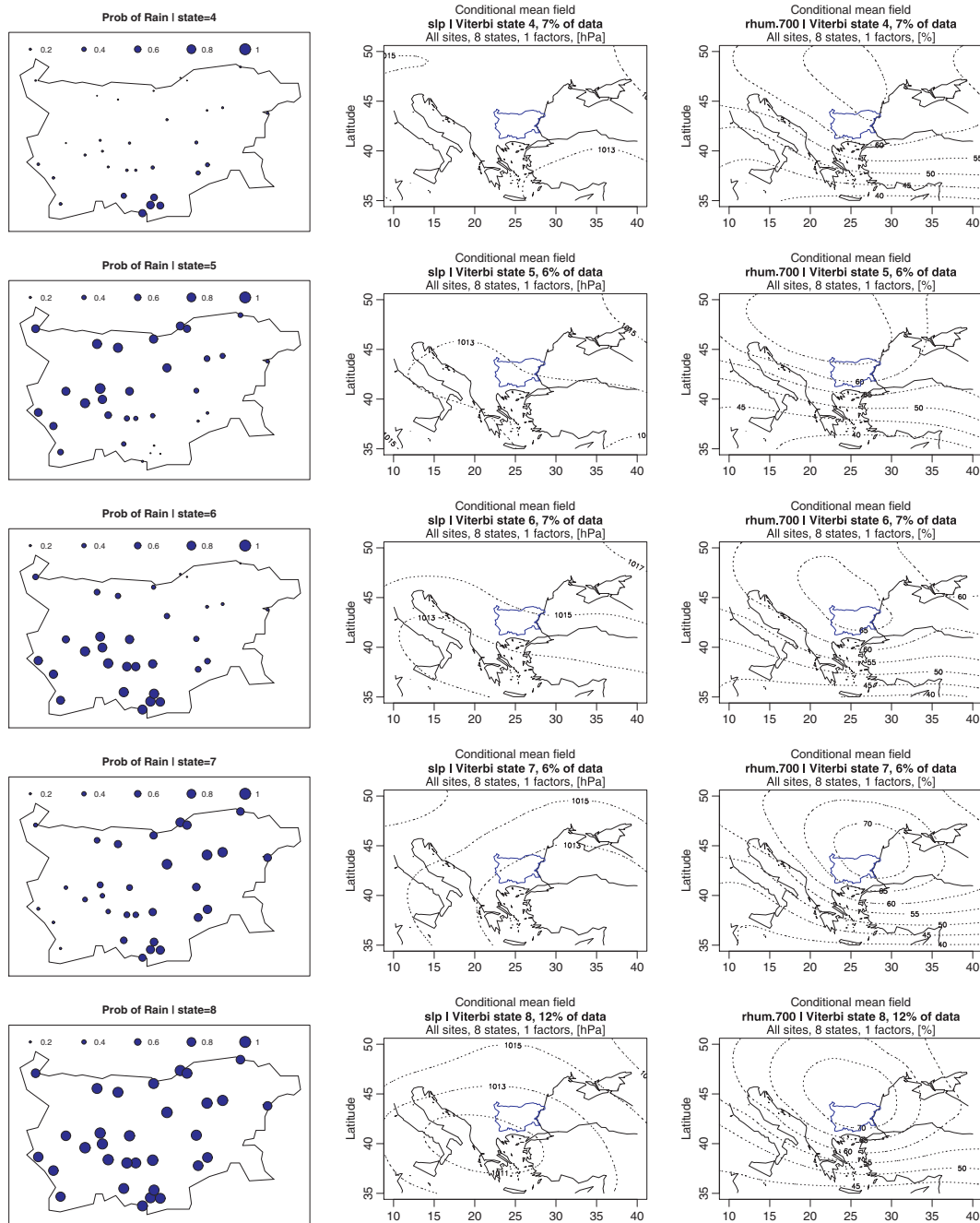


Figure 5.63: Continuation of Fig. 5.62, for states 4 to 8 (rows).

due to southwestern flow. In such synoptic situations, the precipitations are limited over Western Bulgaria and the slopes of mountain opposite to wind, according to hgt.850 plot. State 3 represents a short-term synoptic situation due to the atmospheric fronts of Baltic cyclones. Here, precipitation is mainly over the North-Eastern part of Bulgaria and the Black sea. Contrary to the other states with precipitation, the pressure field is without gradient and only an upper-level trough marks the process. The states from 4 to 8 are associated with Mediterranean cyclones, centred over South Italy in the mean sea level pressure field and an upper-level trough with different amplitude and tilt in the

geopotential height at 850 hPa. The air flow possesses an east component at the sea level pressure and southwest direction at the upper levels. As regards the 7 and 8 states, the depression area is expanded to the Black sea as marked movements of the cyclone in this direction. Synoptic situations of this type are characterized with precipitations over the whole territory of Bulgaria. The states can be classified according to cyclone evolution phases as initial (states 3 and 6), transitional (state 5 and 8) and final (state 7), some features of the precipitations due to different trajectories of the cyclone (state 5 and 8) or its blocking (state 3 and 6). Thus the sequences of states transitions $5 \rightarrow 8 \rightarrow 3$, $5 \rightarrow 8 \rightarrow 7$, $6 \rightarrow 8 \rightarrow 7$ or $6 \rightarrow 8 \rightarrow 3$ represent realistic well-known synoptic situations of Mediterranean cyclones with trajectories via Aegean Sea.

5.5.4.4 Conclusion

We can confirm that the NHMM is a useful research tool for investigating the relationship between large-scale and local-scale variables, such as precipitation. The advantage of the NHMM in simulation of daily precipitation data is that it can simulate stochastically the effects of large-scale atmospheric circulation on local weather at multiple gauge stations; as a consequence, the generated daily precipitation occurrence sequences are synchronized. Results for a 32-sites network over the territory of Bulgaria indicate that the NHMM can successfully reproduce the at-site and inter-site statistics of daily precipitation. The identified precipitation states provide a regional climatology for Bulgaria, representing the dominant spatial patterns of daily precipitation occurrences. The patterns are related to climate variability via the optimum selection of a small set of atmospheric predictors. Future applications of this technology could be used to assess water resource management in Bulgaria as a function of current and projected future climate simulated by the general circulation models. A computational problem of the NHMMs approach is the model parameters number in case of a larger network stations number which is a serious limitation.

5.5.5 Connections between Circulation Type Incidence and the Modelled Potato Crop Yield in Estonia

Authors: Mait Sepp and Triin Saue

5.5.5.1 Introduction

The natural environment (e.g. trees growth, crop yield, migration of birds and insects) is closely linked to the climate and is directly or indirectly dependent on weather conditions. Often, these parameters are not only depending on one meteorological element, but on a combination of many weather conditions, resulting in moderate correlation with the traditional meteorological parameters (air temperature, precipitation). In that respect, atmospheric circulation types can also be regarded as the integrated form of different meteorological parameters. This analysis aims to study the incidence of general atmospheric circulation on the potato crop yield in Estonia and to search how spring, summer, and yearly circulation conditions affect the yields of early and late potato varieties in three different locations in Estonia for three stations representing different climatic conditions (coastal areas, the Baltic Sea islands and inland Estonia).

5.5.5.2 Data and methodology

The study analyses all classifications for the COST733CAT 1.2 defined on domain 05. The potato data include time series of meteorologically possible yield (MPY), calculated using the potato production process model POMOD (SEPP and TOOMING, 1991; KADAJA and TOOMING, 2004). MPY is the maximum yield that certain plant species and varieties are able to produce in the given meteorological conditions which enables us to estimate the agro-meteorological resources of different years and locations. Its long-term average describes the agro-climatic resources. The input data for POMOD are the daily meteo-data (air temperature, precipitation, solar radiation), the value of the initial water storage in the soil (or the date when the soil moisture fell below the field capacity), the date for a stable temperature rise over 8°C, the dates for the first and last night frosts (= -2°C), and the date of the stable temperature fall under 7°C. The different locations are described by their geographic coordinates and hydrological parameters of the soil (wilting point, field capacity and maximum water capacity). The applied characteristic parameters for potato varieties are the parameters of photosynthesis and respiration, as well as the growth functions. For this study, the list of data was derived from the characteristic data system of three Estonian meteorological stations (Tallinn, Tartu, Kuressaare) and the biological parameters of two potato varieties (early Maret, late Anti SAUE and KADAJA, 2009). Of the three meteo-stations used, Tartu is located in the mainland and has a relatively continental climate; Kuressaare is located in the West-Estonian archipelago and clearly represents the maritime climate; Tallinn lies on the Estonian northern coast and there is also maritime climate, but not as clearly expressed as in Kuressaare.

To find the connections between MPY and the general atmospheric circulation, linear correlation analysis was applied and significance at the 99% level calculated by the Student t test. The results of the correlation analysis are evaluated in two aspects. Firstly, we studied which classifications describe the potato crop yield distribution better, by calculating the proportion of Circulation Type (CT) of each classification with a

significant correlation with MPY. This is repeated for spring, summer and the whole year, and for each potato variety. Secondly, the sign of the correlation associated with CT are considered separately by analyzing the composite mean sea level pressure (MSLP) maps associated with each CT.

5.5.5.3 Results and discussion

Results show that generally, occurrence of CT is more often negatively correlated with MPY, i.e. occurrence of CT is linked to decrease in the potato crop yield (Tab. 5.20). There is a large seasonal and spatial variation in the results. The highest number of significant correlations is found in the summer with MPY in Kuressaare, and in particular with the late potato variety Anti (Tab. 5.20); other varieties have ten times less significant correlations.

Table 5.20: Total number of statistically significant circulation types over all classifications and dominating pressure areas over the domain. Abbreviations: Trt – Tartu, Tln – Tallinn, Kur – Kuressaare, Mar – early potato type Maret, Ant – late potato type Anti, Y – year, Sp – spring, Su – summer, neg – negative correlation, pos – positive correlation, L – low, H – high, Northern/Southern – the general direction of air masses that flow into Estonia depending on the position of pressure areas. ? – situations where the dominating pressure area or the direction of air masses cannot be determined.

	<i>TrtMar</i>	<i>TlnMar</i>	<i>KurMar</i>	<i>TrtAnt</i>	<i>TlnAnt</i>	<i>KurAnt</i>
Y/neg	12/L	9/L	18/H	27/L	11/Northern	94/H
Y/pos	1/L?	3/L	28/H-L	1/L?	8/L	58/L
Sp/neg	17/L	17/L	11/L	15/L	2/Southern?	–
Sp/pos	5/H	1/H?	2/L?	–	1/Southern?	2/Southern?
Su/neg	11/L	16/H	83/H	10/L	2/?	127/H
Su/pos	3/?	11/L	70/L	2/L	2/?	107/L

In spring, there are only few CT with significant correlation with MPY, except for the inland station, where the early potato variety is sensitive to the spring CT. This could be because MPY is calculated from the date when the temperature rises and stays over 8°C, the earliest planting date generally after 1 May, and hence, the calculated MPY is affected by the weather conditions of March and April only by the water stored in the soil at the beginning of the growing season. The number of significant correlations when calculated over the whole year is similar to that calculated over the summer, probably because the CT-s of other seasons (winter and autumn) do not have any significant impact on MPY and the influence of CT-s over the vegetation period cumulates in yearly data.

One can conclude from the analysis that all CTs with positive (or negative) correlations with MPY are associated with similar large-scale atmospheric conditions well represented by the composite MSLP maps of different classifications. Usually, 2–3 (or up to 5) CT with dominant low pressure conditions with their centre in slightly different locations are those with negative correlation with MPY in Tartu and Tallinn. They are characteristic of a westerly flow above Estonia, and rainy, cooler weather typical for the

summer. Similarly, 2–3 CT with dominant high pressure over the Baltic Sea show significant strong negative correlation with MPY in Kuressaare. Such conditions are typical of anti-cyclone over the northern part of the domain and eastern or north-eastern winds dominant in Estonia, and are characterized by sunny weather and temperatures above average, possibly associated with lack of water and potato growth suffering from drought in specific habitats, such as Kuressaare.

5.5.5.4 Summary

- 1 Those types that affect the crop yield negatively clearly stand out from the circulation types.
- 2 Circulation Types have more links with potato yield in Kuressaare (maritime climate), with early potatoes those most often correlated with CT.
- 3 Spring CT are not well correlated with potato yield in general, but early potatoes show negative correlations with CT with dominant low pressure as such CT are associated with more cyclones, cooler weather, lower soil temperature and excessive humidity hence stopping potato growth.
- 4 Correlation with summer CT show clear regional differences: in coastal locations (Tallinn, Kuressaare) high-pressure CT are negatively correlated with MPY as they are associated with higher temperatures and drought; in Tartu (in land), it is low pressure dominated CT which are negatively correlated with MPY, as this brings excessive humidity not good for potato growth. Results over the whole year are similar to those of summer, except for Tallinn.

5.5.5.5 Recommendations

- **Family of algorithms**
At least one type in each circulation classification have a strong significant correlation with either the frequency of the yearly sum, spring or summer, and with MPY of at least one potato crop variety, regardless of the algorithm. But there is no classification among them which would correlate with MPY of all three meteorological stations at a time. Slightly better results are given by the classifications that have been grouped by the main components. We also would like point out classifications that have been grouped by the self-organizing maps. Here the NNW family classifications have given noticeably poor and clearly unrealistic results. In the other hand SANDRA and SANDRAS performed highly above the average.
- **Number of classes** Classifications with a low number of classes (9) seem to overall perform best (especially CKMEANSC09 and SANDRAC09), except for few algorithm which are associated with the lowest number of significant correlations (KHC09, LITADVE, NNWC09, WLKC09). But in general the number of classes does not matter since usually high correlations are performed by CTs with similar MSLP maps of classifications that have different number of CTs. As a conclusion, we suggest to use as many classifications as possible for similar analysis because different classifications may reveal different links between natural environment and climate.

5.5.6 Storminess and coastal erosion in Spain

Author: Domingo Rasilla Alvarez

5.5.6.1 Introduction

Located on the south-western fringe of Europe, the Iberian Peninsula experiences a winter climate largely dominated by the effects of the mid-latitude circulation. Although located far from the main Atlantic storm track, episodes of storminess are relatively frequent, but unlike precipitation or temperature, those extremes have received relatively much less attention. However, recent episodes, like those in December 1999 (Lothar-Martin windstorms), January 2009 (Klaus) and more recently in January 2010 (e.g. Xhintya) have repeatedly raised public and scientific interest in this phenomenon. Variations of storminess are important in considering the regional consequences of the climate variability for our study area and become one of the most important natural hazards, with impacts on a wide range of environmental processes (coastal erosion, flooding) and human activities (e.g. fisheries, forestry, transport).

The anthropogenic global warming is expected to result in a rise in sea-level, accompanied by changes in extreme climate events (frequency and intensity of storms). Such scenario would result in an acceleration of coastal erosion. Evidences of a recent acceleration of the coastal erosion (beach retreat, falling cliffs, infrastructures...) are observed in many coastal areas around the Iberian Peninsula. But many relevant morphogenetic coastal processes result from individual episodes of storminess that can accelerate or mitigate the expected impacts of the global rising trend of average sea levels. A good understanding of the local forcing processes is required in order to assess the impacts of future sea levels on the basis of expected changes in these forcing parameters.

The objectives of this research are the following:

- 1 To compare several proxy indices to identify and quantify winter storms in the study area.
- 2 To give a better understanding of the regional patterns of variables like wind speed and direction, storm surges and waves associated to those windstorms.
- 3 To analyze relationships between winter storms and the large-scale atmospheric circulation.
- 4 To investigate changes in derived processes of storminess such as potentially eroding events.

The results of this research are more elaborated in the following contributions to various international meetings [RASILLA ÁLVAREZ and GARCIA CODRON (2009); FERNANDEZ and RASILLA ÁLVAREZ (2009); CODRON et al. (2009); RASILLA ÁLVAREZ and GARCIA CODRON (2010); RASILLA ÁLVAREZ et al. (2010); GARCÍA CODRON and RASILLA ÁLVAREZ (2010b); GARCÍA CODRON and RASILLA ÁLVAREZ (2010a)].

5.5.6.2 Data and methods

For this study, both observations and modelled data are used. The former exists out of (a) oceanographic data: sea level residuals (tide gauges), significant wave height,

wave direction and wave period (buoys) (Instituto Español de Oceanografía, Puertos del Estado, SONEL (System d’Observation du Niveau de Mar)) and (b) meteorological data: synop reports from meteorological stations (sea level pressure, wind speed and direction). The modelled data consist out of (a) oceanographic Hindcast data: SIMAR 44 (Puertos del Estado), ECMWF ERA40, ERA Interim data of sea level residuals, significant wave height, wave direction and wave period (buoys), (b) atmospheric data: NCEP Reanalysis, ECMWF ERA40 Reanalysis, ERA Interim Reanalysis data of sea level pressure, 10 m u and v wind components and (c) storm tracks and cyclone statistics (CDC Map Room Climate Products Storm Track Data). (http://nsidc.org/data/docs/daac/nsidc0423_cyclone/index.html #Serreze_1997).

The methodology of the research follows several steps. First of all, a storm identification procedure, originally devised by DONAT et al. (2009), was modified to be applied to the study area. Criteria for extreme storminess:

- 1 99th percentile of average pressure.
- 2 99th percentile of geostrophic wind speed.
- 3 99th percentile of modelled wind speeds (NCEP REANALYSIS).
- 4 Gale percentile of index > 35.

The estimation of the potential coastal flood/erosion induced by storms was simulated on a theoretical (intermediate) beach profile. Potentially eroding events were identified on the bases of the peak over threshold method (PoT) and the 99th percentile of the 6 hourly total water levels, using 48 hours to discriminate independent events.

- 1 Storm surge: short term increase of water levels (inverse barometer effect plus wind piling up).
- 2 Wave run-up: maximum vertical extent of wave up rush on a beach or structure above the water level.
- 3 Total water level: based on the addition of average sea level with the astronomical tide and the storm surge (increase in the water level by the inverse barometer effect and the force of the winds).

The atmospheric environment associated to winter storms has been analyzed combining a Eulerian approach (circulation pattern catalogue) and a Lagrangian technique (objective storm track approach). The circulation pattern catalogues were obtained combining several approaches: one was the automated Lamb Weather Typing approach (JENKINSON and COLLISON, 1977); other catalogues were obtained combining multivariate statistical techniques [YARNAL (1993); COMRIE (1996)], like Principal Component Analysis to reduce the multicollinearity of the initial database, and clustering to group the results of the PCA. Regarding cluster analysis, an attempt was made to compare the results of a very popular algorithm, called K-means, with a new algorithm, the SANDRA (Simulated Annealing and Diversified Randomization), both included within the COST733CLASS software. A discriminant analysis was used to verify the goodness of each classification.

Later, the performance of each circulation type to explain the magnitude and spatial patterns of the target variables was assessed using several methodologies. A 2-sample Kolmogorov-Smirnov [by HUTH, Chapter 4.3] was used to test the equality of the distribution of the target variables – wind speed, storm surges, wave direction and height – under a synoptic pattern against all others. A χ^2 test was applied to test the significance of the occurrence of extreme events by synoptic type.

5.5.6.3 Results and Summary

The comparison between several proxy indices for storminess highlights the primacy of the geostrophic wind speed threshold and the Gale Index. Both criteria are capable to identify most of the strong wind events (in comparison with modelled and observed wind speed), although some discrepancies appear. The Gale Index use to emphasize the role of close cyclones, usually systems of smaller size than the typical ones of northern Atlantic, while the geostrophic wind index identifies more accurately the events associated to large Atlantic systems, following a SW–NE track.

The synoptic climatological approach provides a viable framework to link atmospheric variability and storminess conditions, except where meso-scale circulations (Gibraltar Strait) are the dominant forcing. Several stormy conditions are identified and classified. Stable conditions, due to the expansion of the Azores High towards the Iberian Peninsula or the Western Europe, accompanied by extratropical disturbances tracking between the 50–60°N parallels, usually do not create severe storm conditions, except along the Northern coast of the Iberian Peninsula, due to westerly and northwesterly winds; storm surges are relatively moderate and waves are characterized by swell conditions (long periods). In some cases, the storms can evolve as secondary cyclones, crossing the area southward of the 50°N parallel.

The most frequent pathway of the cyclone systems associated with severe storms over this area usually begins at eastern or central Atlantic, sometimes as a secondary low, following two main pathways: (a) a SW–NE and then turning down to SE, affecting the Iberian Peninsula by a NW flow and (b) a SW–NE track whit a dominating westerly or southwesterly flow. The mean intensity of the systems reaches its maximum along the central Atlantic, usually between the 40°–50°N parallel. Strong winds are observed along the complete Iberian Peninsula, with the highest storm surges and wind waves along the western coast of the Iberian Peninsula and the Gulf of Cádiz area. Storms tracking southward the 40°N parallel only cause some problems in southern Portugal and Gulf of Cádiz area. The Mediterranean area suffers the worst conditions during easterly-northeasterly wind events, usually dominated by local disturbances formed on the Western Mediterranean basin (Gulf of Genoa cyclones, accompanied by orographically enhanced winds such as the Mistral/Tramontana wind. Finally, some strong winds are observed with a weak synoptic forcing in the Alborán Sea-Gibraltar Strait area, locally known as “Levante”; this wind is the result of a combination of orographic and mesoscale atmospheric processes, and the synoptic pattern classification methods usually do not discriminate very well their occurrence and characteristics.

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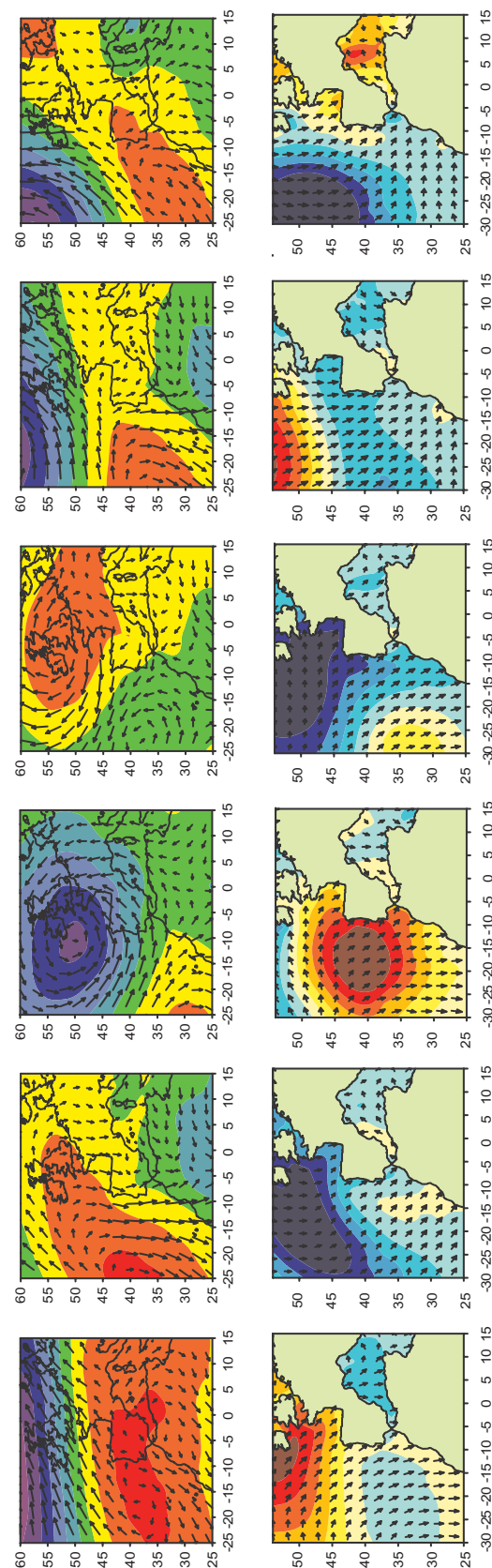


Figure 5.64: Circulation patterns resulting from a SANDRA clustering (upper row) and wave height anomalies corresponding to each circulation pattern.

Some differences in the state of the NAO index arise from the comparison of storms identified by both. Most of the extreme storms identified by the Gale Index correspond to a cyclonic circulation (LWT C) with the predominance of a moderate negative NAO phase (at daily scale). Frequencies of NAO indices on windstorms identified by the analysis of the geostrophic wind speed display values moderately negative (SW) or clearly positive (W and NNW).

The results show a long term increasing trend in the frequency of high water levels and potentially eroding events (total water level above 99th percentile). However, the forcing mechanisms follow different trends:

- 1 A long term increase of average sea level in the area (about 2 mm /yr).
- 2 A reduction of the importance and magnitude of the storm surges because of the long term reduction of strength and frequency of the synoptic circulation patterns conducive to anomalous increase of water levels. The main forcing of the storms surges is the inverse barometer effect, linked to deep extratropical disturbances crossing the Gulf of Biscay area, below the 55°N parallel. Winds are a secondary forcing: the narrow continental shelf of the northern coast of Iberia does not enhance the wind stress during the occurrence of onshore winds.
- 3 Wave run up: most of the extreme events result from strong westerly winds blowing from a distant fetch, belonging to extratropical disturbances tracking between the 50–60°N. No significant trend in the frequency of the disturbances or in the strength of the geostrophic flow was observed over the Gulf of Biscay area.

Extreme storm surges and extreme wave run up events are relatively independent phenomena from the point of view of the atmospheric mechanisms (Fig. 5.65).

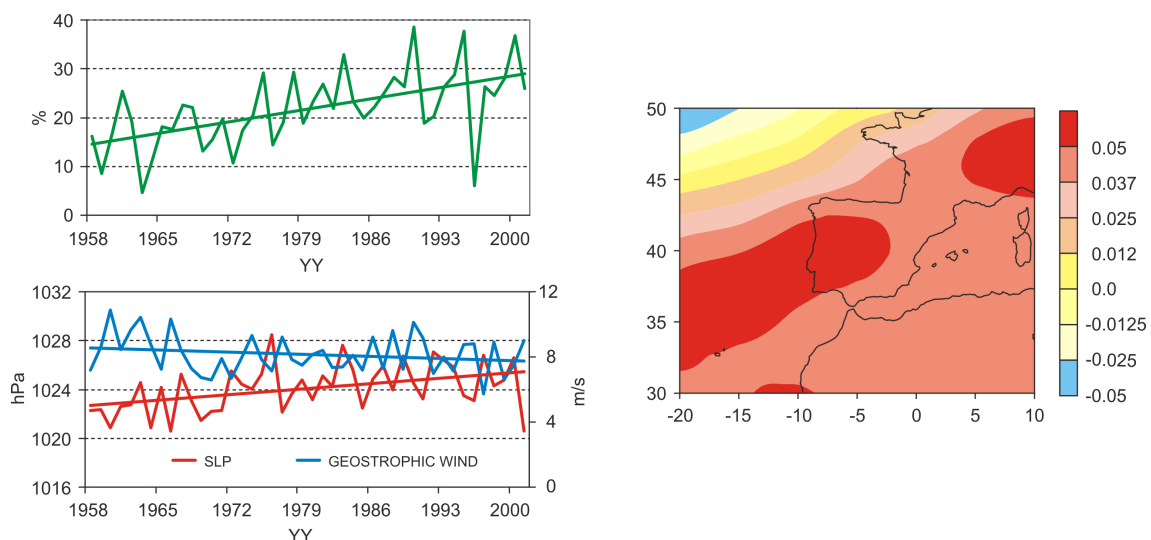


Figure 5.65: Composite sea level pressure and wind vectors corresponding to extreme sea surges (upper left) and wave run up (upper right) and long term trends of selected percentiles of sea level anomalies (lower left) and wave run up (lower right) along the coast of northern Spain.

A comparative analysis of long term trends on oceanographic (wave, storm surge) and atmospheric parameters (wind speeds) shows that most of the evolution of the marine climate is better explained by the within-type changes on the dynamical properties of

the circulation patterns (sea level pressure increase and the enhanced strength of the southerly component of the westerly circulation) rather than changes in the frequency of the circulation patterns.

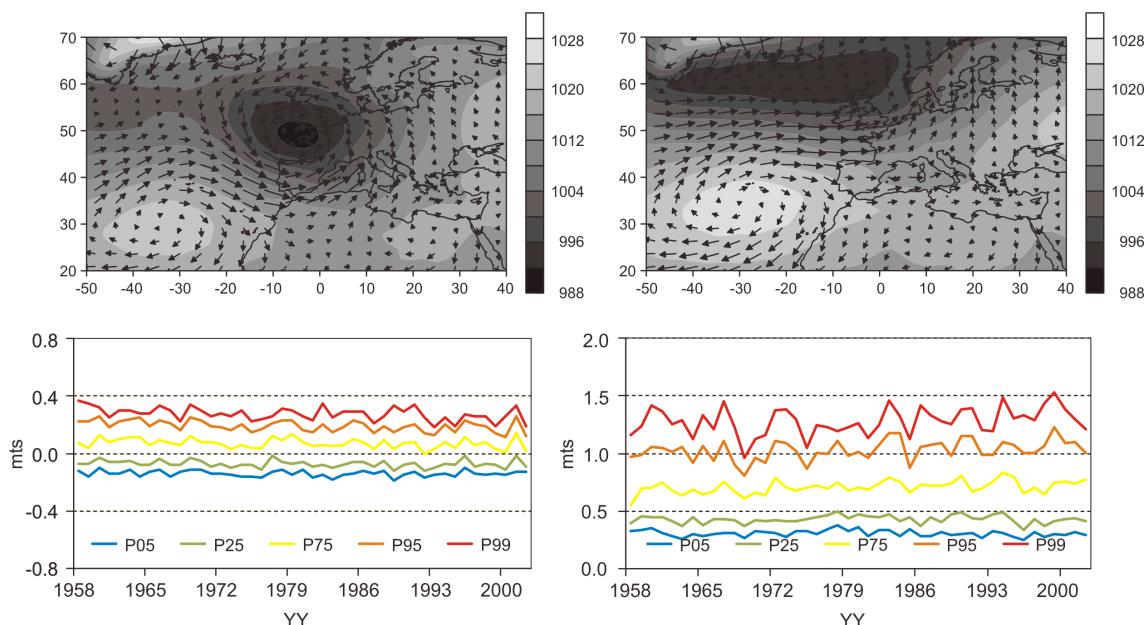


Figure 5.66: Seasonal (ONDJFM) evolution of the frequency (top left) and values of selected circulation parameters, including the slope of the trends (bottom left) within CP3 (right).

5.5.6.4 Conclusions and recommendations

The main mechanism responsible for those storm surges is the inverse barometer effect; surges are a regional (synoptic) rather than local phenomenon, but the signal is enhanced or subdued by the local conditions. Most of the extreme events are caused by extratropical cyclonic disturbances approaching to the Iberian Peninsula through its north-western corner, causing low pressure records and strong winds, but the onshore westerly flow becomes locally offshore in the northern coast of the Iberian Peninsula and the Mediterranean. So, the effect of those winds enhances the abnormal sea level rising to the west, but diminishes the sea level rising in the Mediterranean and Cantabric seas. Extreme wave storms result from strong westerly winds blowing from a distant fetch, belonging to extratropical disturbances tracking between the 50–60°N. Depending of the onshore or offshore direction of the synoptic flow, the associated weather conditions can be very different in areas like the northern coast of the Iberian Peninsula due to the orographic forcing. Finally, it is worth mentioning that, in spite of the trend towards calmer conditions during the last two decades, the long term trend of increase average water levels (about 2 mm/yr) is compensating the weaker storminess.

A comparative analysis between the output of two clustering methods (k-means and SANDRA) included in COST733CLASS software was performed during the research upon the same original data. The Discriminant analysis was used to test the various multivariate statistical procedures. This method is similar to a clustering procedure, but it needs a initial classification catalogue to derive a set of rules to classify new members. For each catalogue a total of 1000 classifications were conducted, selecting randomly 75% of the

cases to derive the statistical rules and 25% for testing. Both methods classified correctly most of the cases, although the degree of matching was superior for SANDRA (94–98% against 92–96%). However, the DOS version of SANDRA is considerably slower than K-means. Lagrangian and eulerian approaches are complementary, and future research should compare the performance of a sequencing synoptic approach against a storm track approach.

5.5.7 Climate change analysis for the Carpathian Basin

Authors: Judit Bartholy, Rita Pongracz, Andreas Philipp, Christoph Beck, Aniko Kern

5.5.7.1 Introduction

The main goals of the presented research were (i) to compare circulation pattern classification methods for Central Europe (COST733 domain 07 covering 43–58°N, 3–26°E) using observed and simulated present climate (1961–1990), and (ii) to analyze the climate change effects on circulation patterns for the same region using different classification methods. The observed climate was represented by the ECMWF ERA40 datasets ([UPPALA et al., 2005](#)).

5.5.7.2 Data and methods

The simulation experiments were accomplished for future climate conditions (2071–2100) using two emission scenarios (A2 and B2) in the frame of the EU-project PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects [CHRISTENSEN and CHRISTENSEN, 2007](#)). High resolution (50km × 50km) simulated daily values of meteorological variables (mean sea level pressure, temperature, precipitation) were obtained from the regional climate model (RCM) outputs of the Danish Meteorological Institute (DMI).

DMI used the HIRHAM4 RCM ([CHRISTENSEN et al., 1996](#)) with 50 km horizontal resolution (the RCM has been developed jointly by DMI and the Max-Planck Institute in Hamburg), for which the boundary conditions were provided by the HadAM3H/HadCM3 ([ROWELL, 2005](#)) global climate model of the UK Met Office. The simulations were accomplished for present day conditions using the reference period 1961–1990 (the model performance of HIRHAM4 is analyzed by [JACOB et al., 2007](#)) and for the future conditions in 2071–2100 using scenario A2 and B2 ([NAKIĆENOVIĆ et al., 2000](#)).

This application study includes the following main steps.

- 1 Establish the classes of circulation patterns from 1961–1990 period of the ERA-40 mean sea level pressure (MSLP) dataset
- 2 Use the same patterns, and run them through the RCM MSLP time series for control
- 3 Use the same patterns and run them through the RCM MSLP time series for future (A2 and B2) conditions
- 4 Calculate the temperature and precipitation statistics associated with each class, and how this statistics change.

For the circulation pattern classification we used the COST733 classification software (version 0.19–17). Twelve different classification methods (grouped into (i) optimization algorithms, (ii) leader algorithms, (iii) PCA based methods, and (iv) threshold based methods as shown in Tab. 5.21 and described in details by [PHILIPP et al., 2010](#)) were applied to the ERA40 daily mean sea level pressure database for 1961–1990 using 9, 18, and 27 weather pattern types. Fig. 5.67 presents the 1961–1990 circulation pattern centroids for DKMEANS and LUND classification techniques, respectively, when using

9 different circulation types. For DKMEANS, the most frequent types were Nos. 1 and 2 (exceeding 15%), and for LUND technique, the most frequent types were Nos. 6 and 9 (exceeding 23%).

Table 5.21: Applied classification methods. The main features of these classification techniques are described in [PHILIPP2010].

<i>Optimization algorithms</i>	
DKMEANS	k-means clustering by dissimilar seeds
KMEANS	k-means clustering
SANDRA	simulated annealing and diversified randomization clustering
SANDRAS	classification of sequences of days with SANDRA
HCLUST	hierarchical clustering
<i>Leader algorithms</i>	
LUND	classical leader algorithm
KH	Kirchhofer types
<i>PCA based algorithms</i>	
TPCA	principal component analysis in t-mode
KRUIZ/P27	Kruizinga empirical orthogonal function types
PCAXTR	principal component analysis extreme scores
<i>Threshold based algorithms</i>	
LIT	Litynski advection and circulation types
GWT	Grosswetter-types or Prototype classification

5.5.7.3 Results and Summary

The different classification techniques may be compared and evaluated using various measures (BECK and PHILIPP, 2010). Here, only two applied criteria for separability and within-type variability of classifications are discussed, namely the explained variation (EV, expressed as percentages) and the within-type standard deviation (WSD) calculated for the mean sea level pressure (MSLP) field of ERA-40 data in Figs. 5.68 and 5.69, respectively.

For EV, the larger the number of patterns, the better the performance of the classification. Winter performance is better than the summer performance for the optimization algorithms and the PCA-based techniques, while for the leader and threshold algorithms summer EV is larger than winter EV. The best performing classification methods are the optimization algorithms with EV larger than 70% in winter and 50% in summer (Fig. 5.68). For WSD, values are decreasing when the number of circulation patterns increases. For all the classification methods, summer WSD is smaller than winter WSD

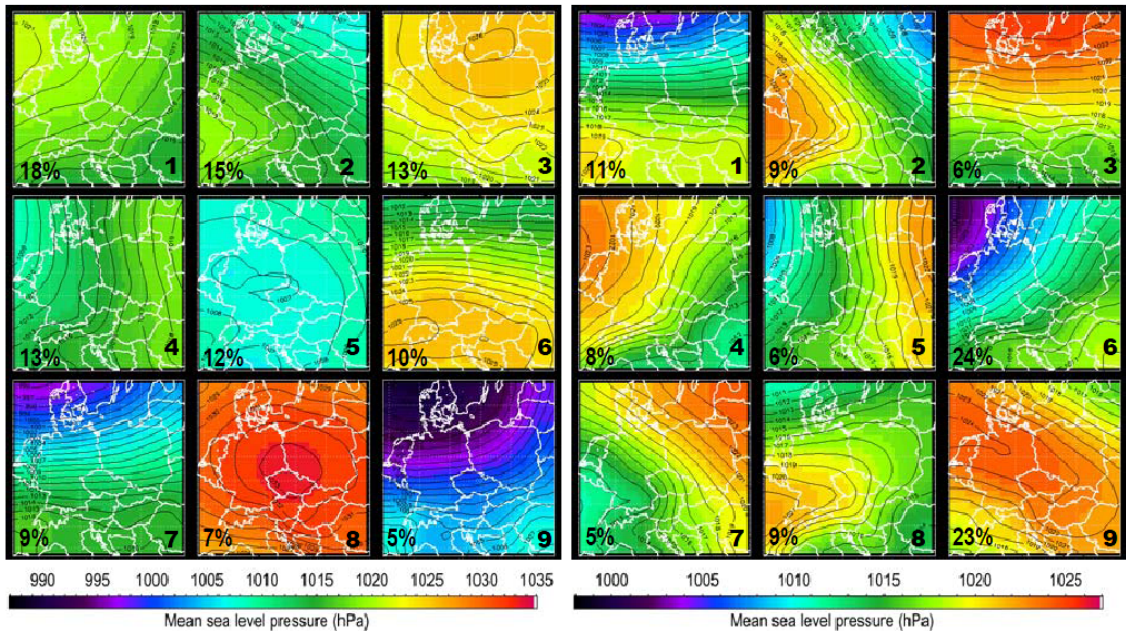


Figure 5.67: Centroids of 9 circulation patterns for DKMEANS (left) and LUND (right) method using ERA40, 1961-1990 period, region 07. The percentage values in the lower left corner indicate the relative frequency of the corresponding pattern.

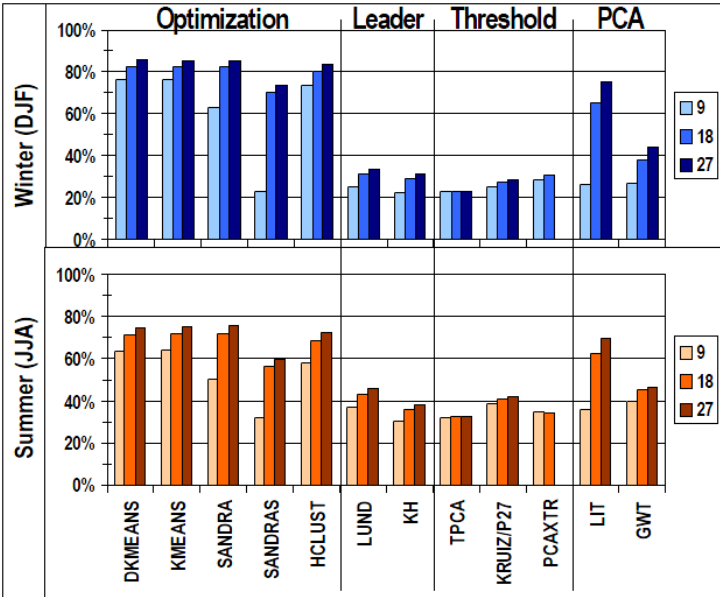


Figure 5.68: Seasonal explained variance of MSLP fields from ERA-40 dataset, 1961-1990, winter (upper panel) and summer (lower panel).

(Fig. 5.69), which is due to the smaller overall variability of summer climatic conditions. The best performing techniques are the optimization algorithms (DKMEANS, KMEANS, SANDRA, HCLUST) with WSD values smaller than 6 hPa and 4 hPa in winter and summer, respectively.

The resulting circulation pattern types from 1961-1990 classifications of the mean sea

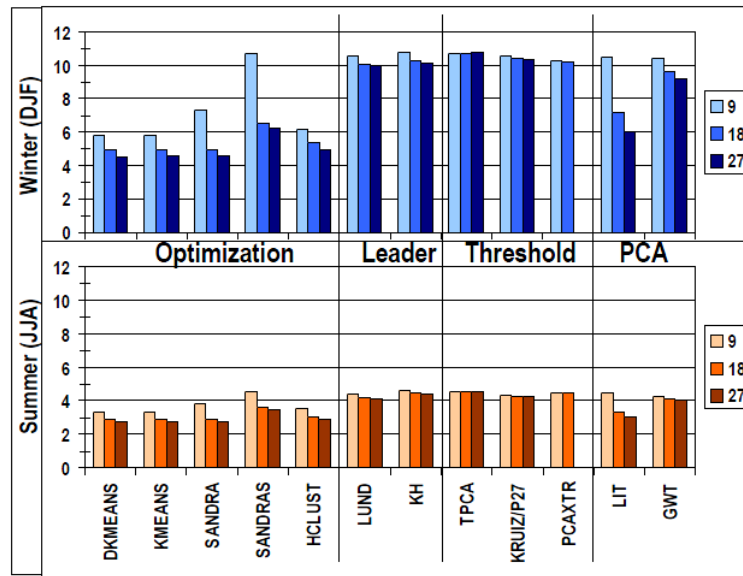


Figure 5.69: Seasonal MSLP fields from ERA-40 dataset: within-type standard deviation, 1961–1990, winter (upper panel) and summer (lower panel).

level pressure fields were applied to RCM MSLP projected for the 2071–2100 period for both A2 and B2 scenarios. Frequency distribution changes of circulation pattern types were analyzed in the selected domain by 2071–2100 period for both A2 and B2 scenarios relative to the 1961–1990 reference period (RCM control). In order to maintain a reasonable extent of this case study, this analysis for only one classification technique is shown here. We selected DKMEANS among the 5 optimization algorithms used in the analysis, and Fig. 5.70 illustrates the results. The relative frequency values of different circulation pattern types using the DKMEANS–C09 classification technique are not projected to change very much for either scenario (the difference does not exceed 2%). Fig. 5.70 also compares the occurrence of different classes for ERA-40 and simulated control data. In some classes (No. 1 and 6) the difference between the relative frequencies are about 3%, while for other classes (No. 2, 4, and 7) it is close to zero.

Furthermore, temperature anomaly and precipitation pattern changes were evaluated in the Carpathian basin (covering 45–49°N, 14–27°E) for each circulation pattern types using all the selected classification techniques (PONGRACZ et al., 2010), but reported here only for DKMEANS–C09. For both winter and summer future anomaly fields are projected to be warmer by the end of the 21st century than the present climate due to the regional warming (BARTHOLY et al., 2007, 2008). But the warming, however, is not identical for all DKMEANS–C09 classes, as illustrated by Fig. 5.71 which summarizes the mean winter and summer increase of temperature anomaly for Hungary for each class. For the B2 scenario the winter/summer warming is about 1.5–3°C/2–5°C, while warming is larger for A2 scenario (2.5–5°C/3–5.5°C). The largest warming is projected for circulation pattern types 8 in winter, and 8 (B2) and 9 (A2) in summer.

Precipitation is far more variable in space and time than temperature. Furthermore, the topography of the regions is key factor in determining the precipitation, thus, in the higher Carpathian and Alps mountains the precipitation is larger than in the lowlands of Hungary (PONGRACZ et al., 2010). Fig. 5.72 summarizes the spatial mean seasonal precipitation change for Hungary for each circulation pattern type using DKMEANS

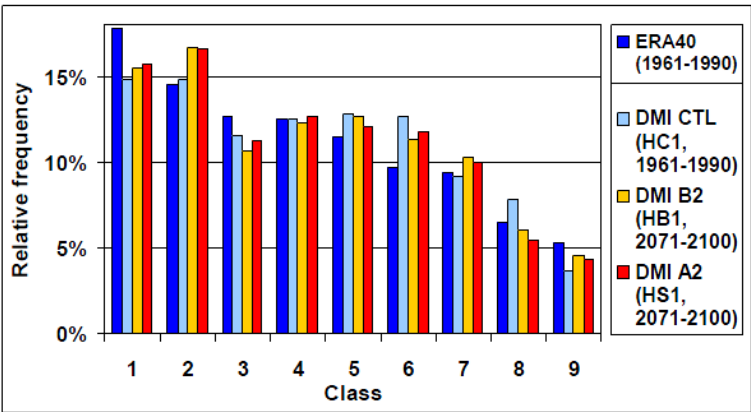


Figure 5.70: Relative frequency occurrence of DKMEANS-C09 classes established using (i) ERA-40 data (1961–1990); (ii) RCM-control (1961–1990); (iii) RCM-A2 (2071–2100) and (iv) RCM-B2 (2071–2100).

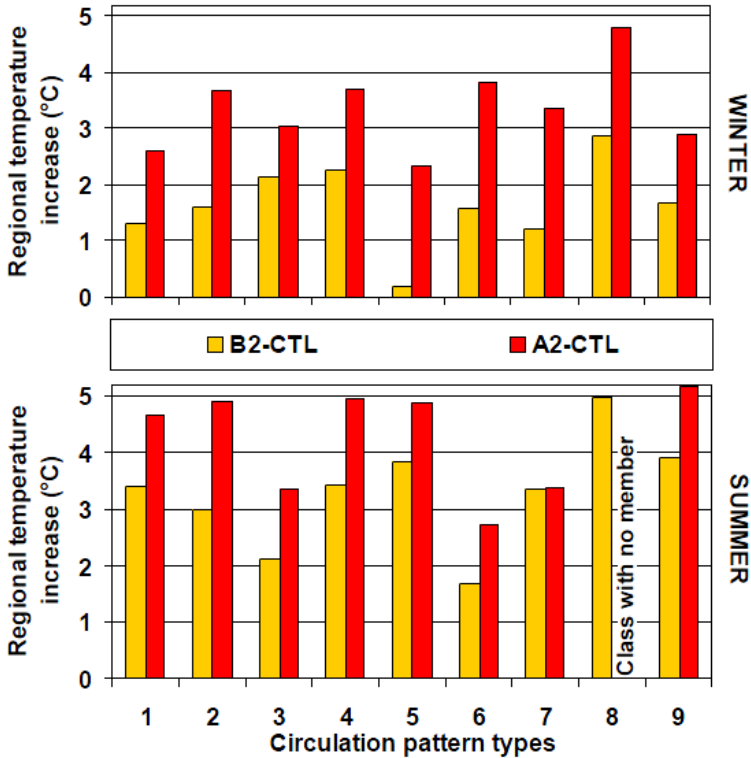


Figure 5.71: Projected mean seasonal temperature anomaly changes in Hungary by 2071–2100 for each circulation pattern type using DKMEANS classification technique (compared to CTL, 1961–1990).

classification technique. The results suggest that winter/summer is expected to become wetter/drier compared to the reference period, 1961–1990, as identified in previous studies (e.g. [BARTHOLY et al., 2007](#)). Circulation pattern types 5, 1 and 9 are associated with wet winter climatic conditions in Hungary in the control RCM simulations (1961–1990 [PONGRACZ et al., 2010](#)), and are projected to become even wetter in the future (2071–2100 in case of either scenario, [Fig. 5.72](#)). As far as the summer drying, the largest

changes are projected in case of circulation pattern type 9 (the decrease is likely to exceed 1.1 and 1.4 mm/day for B2 and B2 scenario, respectively). This circulation type, characterised a strong zonal/cyclonic isobar structure in Fig. 5.67, was the wettest one in Hungary in the control RCM simulations (1961–1990). However, circulation patterns associated with past dry summers are also expected to become even drier by the end of the 21st century (as shown in the lower panel of Fig. 5.72). The projected drying trend for A2 is generally larger than that for B2, which might be due to the larger warming trend of A2 [IPCC2007].

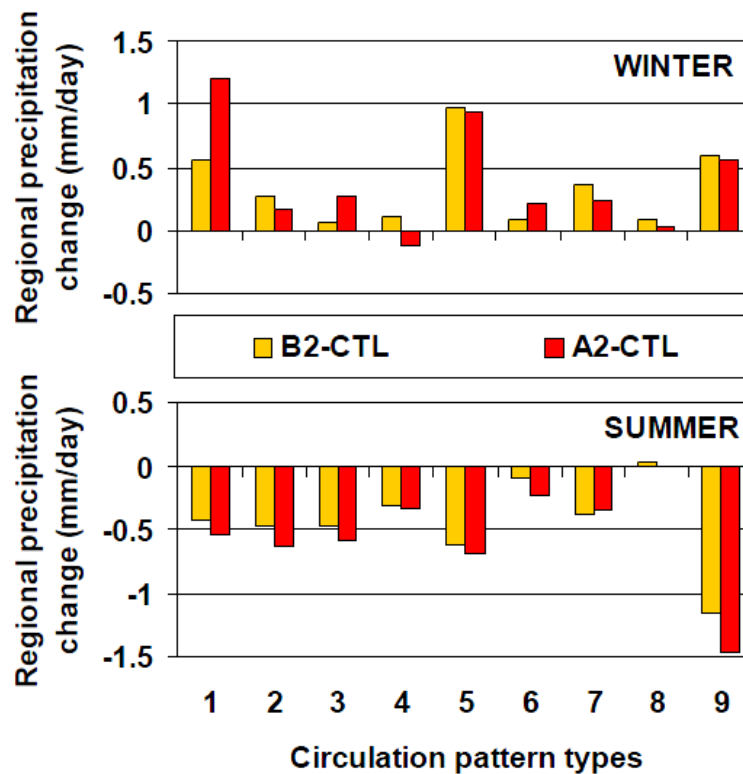


Figure 5.72: Projected mean seasonal precipitation anomaly changes in Hungary by 2071–2100 for each circulation pattern type using DKMEANS classification technique (compared to CTL, 1961–1990).

5.5.7.4 Conclusions

On the basis of the presented analysis the following main conclusions can be drawn. Considering the explained variance (EV), the larger the number of patterns in a given classification method, the better the performance of the classification. Seasonal differences can be found in this respect: (i) the winter performance is better than the summer performance in case of the optimization algorithms and the PCA-based techniques, (ii) the summer performance is better than the winter performance for the leader and threshold algorithms, (iii) the best performing classification methods are the optimization algorithms with EV larger than 70% in winter and 50% in summer. In case of within-type standard deviation (WSD) the values are decreasing as the number of circulation patterns increases. For all the classification methods, summer WSD is smaller

than winter WSD, which is due to the smaller overall variability of summer climatic conditions. The best performing techniques are the optimization algorithms with less 6 hPa (in winter) and 4 hPa (in summer) WSD values.

DKMEANS-C09 is selected as an example for the climate change analysis in the Carpathian basin. In case of B2 scenario the winter (summer) warming is about 1.5–3°C (2–5°C) by the end of the 21st century, and it is larger for A2 scenario: 2.5–5°C (3–5.5°C). The results suggest that winter (summer) is projected to become wetter (drier) compared to the reference period, 1961–1990.

5.5.8 Conclusions and recommendations – subgroup “Other applications”

The case studies presented in this chapter include a range of different analyses from isotopic composition, over circulation type dependent model evaluation to crop yield modelling and coastal erosion. All of them approach the large-scale circulation types in a different manner and on distinctly different space- and time-scales. This makes the generalisation of the conclusions impossible so that for this section, only some major findings with respect to the large-scale circulation methods are listed in Tab. 5.22.

Table 5.22: Summary of the results from the case studies in the subgroup “other applications”. The symbols refer to: (1) – –/++: A lower/higher number of classes improve the results; (2) +/–: improvement/deterioration of the results; (3) ≈: no conclusive evidence for a significant impact and (4) blank: This criterion is not tested.

<i>Cat.</i>	<i>Variable</i>	<i>algorithm</i>	<i>Preferred</i>	<i>Addt'l.</i>	<i>Seasonal</i>	<i>Sequence</i>
<i>version</i>	<i>tested</i>	<i>(class)</i>	<i>domain</i>	<i>nr. of</i>	<i>input</i>	<i>?</i>
			<i>(domain of</i>	<i>classes</i>	<i>variable</i>	<i>?</i>
			<i>interest)</i>			
1.2	Isotopic signature	OPT		++		
1.2	Potato crop yield	≈		--		
1.2	Storminess	SANDRA				
Class0.19	MSLP, T and precip (climate change)	OPT		++		

5.6 Conclusions and recommendations – Working Group 4

The main goal of WG4 in COST733 was to apply the circulation type classification methods developed in WG2 on a range of climatological and environmental phenomena. Hence, 31 case studies are reported, structured in 5 subgroups dealing with climatology, air quality, meteorological and hydrological extremes, forest fires and other applications. Although the list of applications is long, it is by no means exhaustive, as other types of applications (e.g. phenological, biometeorological, ...) are not tested.

A strong interaction between the other COST733 working groups 2 and 3 (Chapters 2 and 3) partly defined the activities within WG4. As WG2 developed a first main version 1.2 of the catalogue (cf. Section 3.3) in July 2008, most of the applications were tested with this version. Afterwards, based on the feedback provided by WG3 and 4 (e.g. use of additional input variables, sequencing, ...), the COST733CLASS software (cf. Section 3.4) was extended with new features resulting in a new version of the catalogue (v2.0). Unfortunately, not all members of WG4 were able to fully test catalogue v2.0, and it is important to carefully consider results and recommendations when interpreting the case studies described in this chapter.

The performance of the circulation type classifications is expressed quantitatively using the measures suggested by WG3 (Chapter 4) and some case-study specific measures. This provides insight in the performance of a classification method for each specific application and location. Note however, that no general set of conclusions or recommendations can be given for a specific application due to the number of Circulation Type Catalogues (CTCs) provided by WG2, spatial differences (location and size of region of interest), the evaluation measures used and the choice of input variables. This means that each case study result tends to be very specific and cannot be generalized.

However, the work done in WG4 resulted in set of guidelines that are recommended when using circulation types for a specific application:

- Carefully consider the input variable(s) used to construct circulation types, as it (they) should be directly related to the application of interest,
- it is important to consider several classification methodologies, as individual catalogues are rarely representative,
- no classifications method nor family of algorithms has shown systematic strongest or weakest links with any of the considered applications,
- the optimal number of classes in a classification depends on the application and to some extent to the evaluation metric,
- the optimal size of the defined domain of the classification depends on the application and type of classification algorithm,
- specific seasonal definition of circulation types is only beneficial for specific applications.

Overall, the results in this chapter demonstrate that the circulation classifications are useful for a large range of environmental and meteorological/climatological science applications, but results are very specific to the type of application considered.

Summary, Recommendations and Conclusions

Main author: Ole Einar Tveito

6.1 Summary

During the course of the action a wide selection of different methods for classification of atmospheric circulation has been evaluated. A first survey of applications of circulation type classification methods revealed that 65 methods were applied among the respondents. Some of these were at an early stage discarded from further considerations in the action due to too local dependencies, too few or many types, not relevant input variables (see Section 2.4). Where methods were similar with respect to classification principles a single representative method was selected. It has been important to include a broad selection of methods within each of the classification method categories; subjective, threshold, PCA, leader algorithm and optimization algorithms.

As seen in Chapter 1 classification of atmospheric conditions and circulations have a profound tradition. There are several approaches; weather types, circulation types and airmass types. Within COST only truly circulation types have been considered. This ensured a more equal and consistent comparison of atmospheric circulation than if e.g. downscaling and environment-to-circulation (YARNAL, 1993) approaches have been included. These often rely on a calibration against response variables that might have made the objective comparison biased (and unfair).

A fundamental principle with respect to the main objective of COST733, to develop a general classification method for Europe, has been that the classifications should be automated. That means that it should be objective, computerized and transferable to the domain of interest. Therefore it has been important to get the acceptance of the authors of the classifications to include their catalogues into the COST733 dataset.

For the evaluations and analyses the action has defined 12 fixed domains across Europe. The domains were defined in order to represent regions with different synoptic characteristics, different application needs. They also, to a certain extent, represented different spatial scales.

All the methods that were included in COST733 datasets, except the widely used

subjective catalogues included for comparison and evaluation, were applied to establish circulation type catalogues for all the 12 domains. For all methods ERA40 re-analysis fields were used as input data in order to ensure consistency. The time period covered is thus 1957–2002.

Already early in the action the need to collect the classification algorithms into a joint software became an ambition. The result of this extensive effort by WG2 is realized as the COST733CLASS software (see Chapter 3). The software currently includes 27 methods.

During the course of the actions needs of the working groups led to development of flexibility for defining sequencing, seasonality, domain size and input variables. The software also includes basic evaluation statistics for intercomparison of different algorithms.

In the action the various classifications were applied and evaluated by WG3 and WG4 for a wide range of different applications (more than 30) that are described in Chapter 4 and 5. Evaluation on different levels, using different approaches such as subjective, basic, climatological and on application level are carried out. Applicability, usefulness, strengths and weaknesses are assessed.

6.1.1 Sustainable results

The results of the action provide a robust sustainable resource for further research, development and application of the Actions objectives and motivations.

- COST733CLASS – the extensive open-source classification software for a large number of (currently 20) automatized circulation type classifications developed. The software also include basic evaluation statistics. The url is <http://cost733.geo.uni-augsburg.de/cost733class-1.2>
- COST733CAT – an extensive directory of predefined classifications. Version 2.0 of COST733CAT circulation type catalogue includes 17 + 1 automatic and 6 subjective classifications for 12 predefined domains. The url is <http://cost733.geo.uni-augsburg.de/cost733wiki/Cost733Cat2.0>
- COST733PLOT – Open access visualization web application providing quick view of centroid maps and statistics. The url is <http://cost733.geo.uni-augsburg.de/cgi/cost733plot.cgi>

6.1.2 Impact, outreach and EU added value

The Action has kept a high scientific standard, providing several key papers on the topic atmospheric circulation classification. HUTH et al. (2008) gave an extensive peer-reviewed review paper on recent developments and applications of circulation type classifications. Other COST733 results have been published in papers, at conferences and workshops.

Typical outreach activities have been:

- Many ‘non-joint’ papers utilize (and benefit from) joint database.
- An outstanding 3-day mid-term conference in Krakow 2008 gathered almost 100 participants giving 80 presentations, including presentations from several international capacities.

- Sessions on ‘synoptic climatology’ at EMS conferences since 2006.
- Sessions on classifications and regimes at EGU conferences since 2009.
- Publication of a Special Issue of the Journal Theoretical And Applied Climatology from EMS 2006 with several COST733-based papers. See also the Bibliography in this Report as well as Appendix D for further COST733-related publications.
- Publication of a Special Issue of the Journal Physics and Chemistry of the Earth (Vol. 35/9–12, 2010), including 29 papers from the Krakow mid-term conference. See also the Bibliography in this Report as well as Appendix D for further COST733-related publications.
- A 5 day training school in Augsburg in April 2010 (23 trainees, 9 lecturers). See Appendix E.

6.2 Recommendations and Conclusions

6.2.1 Not one fit-all-purposes method

It should be rather obvious that such a wide range of different comparisons and evaluation principles and methods, different geographic areas and various purposes and applications areas would not give straight forward unique answers. So the most important answer is that there is no single classification that is superior the others for all possible applications. A strong recommendation is therefore, since individual catalogues are by no means representative, to always consider several classifications for your application. Subjective/manual classifications should be applied with care since they may not be homogenous over time.

6.2.2 Number of types matters

The first evaluation results clearly indicated that the number of types in a classification were significant for its performance. Since the motivation for the action was to compare and evaluate the algorithms it was decided to fix the number of types to ~9, 18 and 27 types. The further examinations showed that the number of types actually had a larger impact on the performance than the choice of classification method. Which number of types that is most suited will depend on the purpose¹⁾.

6.2.3 Domain size matters

The relevance of this additional boundary condition of CTCs for synoptic skill already arose from respective initial analyses within the COST733 Action. Several studies (see, e.g., BECK et al., 2016) have shown that the domain size will significantly influence the results of the resulting circulation types, and thus the characteristics making them effective for different application. Which domain size being most effective will depend on the properties and scale of the target variable and which synoptic atmospheric features that will have an influence. Investigations showed highly variable results for different

¹⁾See also Subsection 4.2.3.2 on page 81

domain sizes, different methods, different regions and different applications²⁾. It is thus not possible to give a general recommendation on which domain size being the most efficient.

6.2.4 Input variables matter

Originally the classifications in COST733 were based on MSLP only. During the action inclusion of several input variables into the classification showed that performance of the classifications improved. The effect of which input variables to include varies from purpose to purpose³⁾

6.2.5 Purpose matters

The choice of method, domain size and number of types are important with respect to which weather and climate characteristics that could be described. The results from the analyses have shown that even though there is no best method some methods show slightly better performance for some response variables than others.

6.2.6 Basic conclusion

A clear conclusion is that the purpose for using circulation classes should decide which classifications to apply since the characteristics of the target process must be reflected by the circulation types. It is therefore recommended to try different CTC methods and setups in order to find the combination of domain size, number of types and algorithm that best fit with your purpose.

²⁾See also Subsection 4.2.3.3 on page 83

³⁾See also Subsection 4.2.3.8 on page 97

Epilogue

Main author: Christoph Beck

In September 2011 – one year after the official end of the COST733 action – the Deutscher Wetterdienst announced to terminate the production of the Hess and Brezowsky Großwetterlagen classification by the end of 2011. This would have meant to cease a continuous time series of daily subjectively determined weather types starting in 1881 that has been used in numerous studies and still is in use for many purposes. In answer to these plans the COST733 network initiated a petition to persuade the Deutscher Wetterdienst of continuing the unique time series of the Hess and Brezowsky Großwetterlagen. Together with interventions from other parties this finally led to the decision of the Deutscher Wetterdienst to provide the Hess and Brezowsky Großwetterlagen classification also in future.

Beyond the rescue of the Hess and Brezowsky Großwetterlagen classification, the COST733 action – although officially ended in September 2010 – still has enduring impact on further advancements in the research field of synoptic climatology in general and in circulation and weather type classifications in particular. This sustained scientific relevance of COST733 stems from

- (1) the widespread use and the continuous maintenance and enhancement of the COST733CLASS software package,
- (2) the frequent utilisation of the COST733CAT data set of circulation type classifications,
- (3) the dissemination of know-how attained in COST733 (e.g. varying approaches for the evaluation of classifications) and finally
- (4) the ongoing scientific collaboration of COST733 participants that for instance is apparent from a number of recent joint publications.

The COST733CLASS classification software, initially established within the framework of the COST733 action to compile and evaluate the comprehensive data sets of circulation type catalogues, has been and still is further developed in several ways. Major new features of the cost733class classification software that have been implemented after the official end of the COST733 action are:

- The inclusion of new additional classification methods (e.g. mixture models),

- the enhancement of existing classification methods (e.g. consideration of mid tropospheric wind in threshold based classifications),
- extensions with regard to data handling,
- the implementation of interactive visualization and control of the classification process.

The enhanced version of the COST733CLASS classification software has been applied to ERA40 reanalysis data to provide a distinctly extended data set of circulation type catalogues (PHILIPP et al., 2016). The COST733CAT v2.0 database now allows for further advanced systematic examination and intercomparison of circulation classification methods, in continuation to the COST733 action. Several analyses on the basis of the new comprehensive data set have already been performed [e.g., PHILIPP et al. (2016); HUTH et al. (2016)].

Being one major achievement of the COST733 action, the COST733CLASS classification software is currently not only used extensively by researchers that participated in the COST733 action but as well by other working groups all over the world. In this context it is also worth mentioning that variants of two circulation type classifications that have been developed or substantially enhanced within COST733 and that are included in the COST733CLASS classification software have been introduced as new automatic classification schemes for operational use at MeteoSwiss (WEUSTHOFF, 2011).

The COST733CLASS classification software is furthermore a substantial element of several ongoing nationally funded research projects which apply circulation type classifications in varying synoptic climatological analyses ranging from investigations of the relationships between circulation types and precipitation extremes (https://www.geo.uni-augsburg.de/en/chairs_professorships/phygeo/projects/klima/WETRAX/) and particulate matter (https://www.geo.uni-augsburg.de/en/chairs_professorships/phygeo/projects/klima/PACLIMBA/) respectively to the validation of climate models with respect to the correct representation of circulation type characteristics (https://www.geo.uni-augsburg.de/en/chairs_professorships/phygeo/projects/klima/VADY/).

Beside such funded research projects manifold vital scientific cooperations between members of the COST733 community do still exist and are visible in form of joint contributions to scientific conferences and joint publications.

A number of recent studies related to the COST733 action appeared in a special issue of the International Journal of Climatology published in 2016.

Specific sessions at the annual meetings of the European Meteorological Society and the European Geophysical Union respectively that have been established by COST733 members serve as important platforms for scientific discussion and exchange related to the field of synoptic climatology in general and circulation type classification in particular.

All in all it can be stated that – beyond its official end – the COST733 action continues to be relevant for the advancement of circulation type classification as a, although traditional, highly relevant and continuously refined approach in modern synoptic climatology.

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- Dimitar Nikolov, National Institute of Meteorology and Hydrology, Sofia, Bulgaria
- Massimiliano Pasqui, IBIMET - CNR Institute of Biometeorology, Firenze, Italy
- Maria Ascuncion Pastor, Instituto Nacional de Meteorologia (INM), Madrid, Spain

- Mario G. Pereira, Universidade de Trás-os-Montes e Alto Douro, Vila Real, Portugal
- Andreas Philipp, University of Augsburg, Augsburg, Germany
- Krystyna Pianko-Kluczynska, Institute of Meteorology and Water Management, Warsaw, Poland
- Rita Pongracz, Eotvos Lorand University, Budapest, Hungary
- Piia Post, University of Tartu, Tartu, Estonia
- Christel Prudhomme, Centre for Ecology and Hydrology, Wallingford, United Kingdom
- Domingo Rasilla Alvarez, University of Cantabria, Santander, Spain
- Thorsten Reinhardt, University of Cologne, Germany
- Triin Saue, University of Tartu, Tartu, Estonia
- Reinhard Schiemann, MeteoSwiss, Zurich, Switzerland
- Axel Seifert, German Weather Service, Offenbach, Germany
- Christoph Selbach, University of Cologne, Germany
- Mait Sepp, University of Tartu, Tartu, Estonia
- Arne Spekat, Climate and Environment Consulting Potsdam GmbH, Potsdam, Germany
- Sabina Stefan, University of Bucharest, Bucharest, Romania
- Lena M. Tallaksen, University of Oslo, Oslo, Norway
- Anna Monika Tomaszewska, Institute of Meteorology and Water Management, Cracow, Poland
- Lyubov Trifonova, National Institute of Meteorology and Hydrology, Sofia, Bulgaria
- Ricardo Trigo, Centro de Geofisica da Universidade de Lisboa, Lisboa, Portugal
- Ole Einar Tveito, Norwegian Meteorological Institute, Oslo, Norway
- Walter Zucchini, Georg-August-University, Göttingen, Germany



List of publications in conjunction with COST733

The following list is mainly based on the compilation which was included in the Final Evaluation Report, submitted in 2010 to the COST Domain “ESSEM” as part of its Section *Scientific Report prepared by the Chair of the Management Committee of the Action*. It contains entries which are also included in the Bibliography section of this report, i.e., which are referenced to in the chapters, as well as other references. Moreover, the list below contains some publications that became available after the end of the COST733 Action.

D.1 Publications

1. Adamczyk R. and Z. Ustrnul, 2007: Rola cyrkulacji atmosferycznej w kształtowaniu zachmurzenia ogólnego na obszarze Polski (Influence of the atmospheric circulation on the total cloudiness formation in the territory of Poland). – *Annales UMCS, Sectio B, Lublin* **61**, 15–23.
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3. Bardossy, A., 2010: Atmospheric circulation pattern classification for South-West Germany using hydrological variables. – *Phys. Chem. Earth* **35**, 498–506 [DOI: 10.1016/j.pce.2010.02.007].
4. Beck, C., 2012: Are there weekly cycles in occurrence frequencies of large-scale circulation types? – *Atm. Sci. Lett.* **13**, 238–243.
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6. Beck, C., A. Philipp and F. Streicher, 2016: The effect of domain size on the relationship between circulation type classifications and surface climate. – *Int. J. Climatol.* **36**, 2692–2709 [DOI: 10.1002/joc.3688].

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11. Cahynová M. and R. Huth, 2007: Short note on inhomogeneities in the Hess-Brezowsky catalogue of circulation types. *Meteorologický casopis (Meteorological Journal)* **10**, 171–174. [Published by the Slovak Hydrometeorological Institute].
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31. —, —, 2010b; Relation between circulation and summer ozone concentration at different European places. – *Wiadomosci Meteorologii, Hydrologii i Gospodarki Wodnej* **54**, 29–45.
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..... D.1 Publications

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D.2 Presentations

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2. —, — and —, 2011: Assessment of Circulation Types Responsible for Winter Severe Weather Events over South-Eastern Part of Romania, using COST733 Catalogues. – EGU 2011, Vienna.
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16. Cahynová, M. and R. Huth, 2007: Stratification of climatic elements in the Czech Republic using atmospheric circulation patterns and within-type climatic trends. Poster Presentation. 7th EMS/8th ECAM, San Lorenzo del Escorial, Spain, EMS2007-A-00312.
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18. —, —, 2009a: Long-term trends in the frequency of atmospheric circulation types in European regions. – European Geosciences Union General Assembly, 19–24 April 2009, Vienna, Austria. *Geophys. Res. Abstr.* **11**, EGU2009-7543-1. (<http://meetingorganizer.copernicus.org/EGU2009/EGU2009-7543-1.pdf>)
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23. —, —, 2010d: Links between atmospheric circulation and recent climatic variability and trends in Europe - A comparative approach using the COST733 classifications database. – 11th Int. Meeting on Statist. Climatology, Edinburgh, UK. Poster Presentation.

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43. Esteban, P., C. Beck, A. Philipp, N. Gallego, I. Moner and J. Gavalda, 2010: Circulation type sequences applied to snow avalanches over Andorra and Catalonia (eastern Pyrenees). – COST733 Final Workshop *Classifications in atmospheric sciences and their applications, present state & future directions*. Vienna, Austria 22–24 November 2010.
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59. Huth, R. and M. Cahynová, 2010a: Climatological evaluation of circulation classifications from the COST733 database based on the Kolmogorov-Smirnov test. – COST733 Final Workshop *Classifications in atmospheric sciences and their applications, present state & future directions*. Vienna, Austria 22–24 November 2010.
60. —, —, 2010b: The use of classifications from the COST733 database to detect effects of 11-year solar cycle on atmospheric circulation over Europe. – COST733 Final Workshop *Classifications in atmospheric sciences and their applications, present state & future directions*. Vienna, Austria 22–24 November 2010.
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66. —, —, —, 2010c: Application of circulation classifications from the COST733 collection to the detection of solar and geomagnetic effects on tropospheric circulation over Europe in winter. – EGU General Assembly, Vienna, Austria. Poster Presentation.
67. —, —, —, 2010d: Solar and geomagnetic effects on the frequency of atmospheric circulation types over Europe: an analysis based on a large number of classifications. – EGU General Assembly, Vienna, Austria. Poster Presentation.
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78. Pastor, A. and M.J. Casado, 2008: Impacto del cambio climático en la distribución de eventos. – XXX Jornadas Científicas de la AME, Zaragoza, Spain.
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83. —, 2010: Pseudo Random Classification of Circulation Patterns - Comparison to Deliberate Methods. – Geophys. Res. Abstr. **12**, EGU2010-14814, EGU General Assembly 2010. Poster Presentation.
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89. Philipp, A., P. Post and O.E. Tveito, 2010: A new version of the database of classifications of circulation types over Europe. – EMS Annual Meeting Abstracts **7**, EMS2010-782.
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91. Popa, F., S. Stefan and S. Andrei, 2010: On the relationship between sea level pressure and upper air structures in severe weather situations using the circulation Catalogues developed within COST733 project.
92. Post, P. and K. Päädam, 2010: Extreme precipitation events in Estonia and associated atmospheric circulation patterns. – EMS Annual Meeting Abstracts **7**, EMS2010-588.

93. Rasilla Álvarez, D. and J.C. Garcia Codron, 2009: Storminess at the Gulf of Biscay: classification and long term trends. *Geophys. Res. Abstr.* **11**, EGU2009-6115. EGU General Assembly 2009.
94. —, —, 2010a: Interannual climate variability and tourism potential along the Gulf of Biscay. – ESF-MedCLIVAR Workshop *Hydrological, socioeconomic and ecological impacts of the North Atlantic Oscillation in the Mediterranean region*. 24–27 May 2010. Zaragoza, Spain.
95. —, —, 2010b: Decadal variability of windstorms in the Gulf of Biscay: classification, trends and links with low frequency patterns. – EGU General Assembly 2010, Vienna, Austria.
96. —, —, 2010c: Circulation patterns and wave climate along the coast of the Iberian Peninsula. – 10th EMS Annual Meeting/8th European Conference on Applied Climatology 13–17 September 2010, Zürich, Switzerland.
97. —, —, 2010d: Evolution of potential flooding/erosion conditions along the coast of the Gulf of Biscay. – COST733 Final Workshop *Classifications in atmospheric sciences and their applications, present state & future directions*. Vienna, Austria 22–24 November 2010.
98. Schiemann, R. and C. Frei, 2007: Alpine mesoscale precipitation variability and weather types - Exploring the value of weather type classifications for precipitation gridding. – 6th ECSN Data Management Workshop, Vienna, Austria, November 20–24, 2007. Poster Presentation.
99. —, —, 2008a: Mapping daily precipitation from sparse station networks: A reduced-space optimal interpolation approach for the Alpine region. – 8th Annual Meeting of the EMS / 7th ECAC, Amsterdam, September 30, 2008.
100. —, —, 2008b: Europäische Entwicklungen in der Wetterlagenklassifikation: Die COST Aktion 733. – Workshop Wetterlagenklassifikation an der MeteoSchweiz, Zürich, 8 July 2008.
101. —, —, 2008c: Alpine mesoscale precipitation variability and weather types - Exploring the value of weather types classifications for precipitation gridding. Poster Presentation. Meeting on *Variability of the Global Atmospheric Circulation During the Past 100 Years*, Monte Verità, Switzerland, 15–20 June, 2008.
102. —, —, 2008d: Weather types and gridding of daily precipitation in the Alpine region (update on Brussels WG4 meeting). – COST733 MC and WG meeting, Ioannina, Greece, 9–10 May, 2008.
103. —, —, 2009a: Die Wetterlagenklassifikationen von COST733 - Wie gut erklären sie Niederschlagsvariationen im Alpenraum? Auswahl von automatischen Wetterlagenklassifikationen. – Workshop II, 9 April 2009, MeteoSchweiz, Zürich.
104. —, —, 2009b: Catwalk. Auswahl von automatischen Wetterlagenklassifikationen. – Workshop II, 9 April 2009, MeteoSchweiz, Zürich.
105. —, —, 2009c: Probabilistic Evaluation of Circulation Type Classifications. – COST733 Workgroup 4 meeting, 11 March 2009, Brussels, Belgium.

106. —, —, 2009d: Probabilistic Evaluation of Circulation Type Classifications. – COST733 Workgroup 3 Meeting, 9 March 2009, Brussels, Belgium.
107. Sepp, M., 2010: On regime shift in the general atmospheric circulation over the Baltic Sea region in winter. – 6th Study Conference on BALTEX, Miedzyzdroje, Island of Wolin, Poland, 14–18 June 2010. In: Reckermann, M. and Isemer, H.-J. (Eds.): International BALTEX Secretariat Publications **46**, 46–47. Geesthacht, Germany.
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110. Spekat, A. and F. Kreienkamp, 2010: The importance of the domain size for circulation classifications. – EMS10 Zurich.
111. Spekat, A., F. Kreienkamp and W. Enke, 2008: Classification with purpose and attitude - do not forget the users of climatological information! – EMS Annual Meeting / European Conference on Applied Climatology (ECAC) 29 September–03 October 2008, Amsterdam, The Netherlands.
112. —, —, —, 2010: Trans Weather Patterns - an extended outlook for the future climate. – COST733 Final Workshop *Classifications in atmospheric sciences and their applications, present state & future directions*. Vienna, Austria 22–24 November 2010.
113. Stefan, S., S. Andrei and F. Georgescu, 2010: Intercomparison between circulation types from GWT18 and WLK027 Catalogues for winter severe weather in south-eastern Romania. – COST733 Final Workshop *Classifications in atmospheric sciences and their applications, present state & future directions*. Vienna, Austria 22–24 November 2010.
114. Ustrnul, Z., 2007: The influence of the North Atlantic Oscillation on mean air temperature at different spatial scales. – 7th EMS Annual Meeting, 8th European Conference on Applications of Meteorology, San Lorenzo El Escorial, Spain, EMS2007-A-00339.
115. Zagouras A., A.A. Argiriou, S. Lykoudis, G. Economou and S. Fotopoulos, 2010: Application of affinity propagation clustering on meteorological data. – COST733 Final Workshop *Classifications in atmospheric sciences and their applications, present state & future directions*. Vienna, Austria 22–24 November 2010.



The Augsburg Training School

E.1 Structure

The Department of Physical Geography and Quantitative Methods at the Institute of Geography, University of Augsburg hosted the COST733 Training School Classifications in atmospheric sciences and their applications which took place 12-16 April 2010. This Section uses excerpts from the Training School Report submitted to COST, which was written by Christoph Beck and Andreas Philipp.

The Organizing Committee consisted of

- Christoph Beck, University of Augsburg, Augsburg, Germany (local organizer)
- Radan Huth, Institute of Atmospheric Physics, Prague, Czech Republic
- Andreas Philipp, University of Augsburg, Augsburg, Germany (local organizer)
- Christel Prudhomme, Centre for Ecology and Hydrology, Wallingford, UK
- Ole Einar Tveito, Norwegian Meteorological Institute, Oslo, Norway
- Stefan Stückrad and Chandrasa Sjamsudin, COST Office, Brussels, Belgium

The following ten lecturers were invited to give courses

- Christoph Beck, University of Augsburg, Augsburg, Germany
- Rasmus Benestad, Norwegian Meteorological Institute, Norway
- Pere Esteban Veà, Snow and Mountain Research Center, Sant Julià de Lòria, Andorra
- Radan Huth, Institute of Atmospheric Physics, Prague, Czech Republic
- Jucundus Jacobeit, University of Augsburg, Augsburg, Germany
- Pavlos Kassomenos, University of Ioannina, Greece

- Thomas Krennert, Zentralanstalt für Meteorologie und Geodynamik, Vienna, Austria
- Jan Kysely, Institute of Atmospheric Physics, Prague, Czech Republic
- Andreas Philipp, University of Augsburg, Augsburg, Germany
- Christel Prudhomme, Centre for Ecology and Hydrology, Wallingford, UK

Trainees

The training course was attended by 22 trainees from all over Europe. 23 participants had been selected and invited by the organizing committee of the training course from more than 60 applications. One invited participant was not able to attend the training course due to illness.

Trainees were mainly young researchers on the advanced PhD or early PostDoc level, most of them working in varying fields of climatology, meteorology and hydrology.

E.2 Introduction

The COST Action 733 Training School was set up to include lectures and exercises given by 10 experts covering a wide range of topics including introductory and overview lectures on the theory of classification methods used in atmospheric sciences, lectures and exercises related to the development and the quantitative evaluation and comparison of circulation type classifications and finally lectures and exercises dealing with the use of circulation and weathertype classifications for different applications (e.g. climate change, hydrology, natural hazards, human health).

A main focus had been set to the presentation of and the practical work with the COST733CLASS software for circulation type classification that had been developed within the COST733 Action.

In addition to the daily lectures and exercises student poster presentations taking place on 3 days offered the opportunity for scientific discussions and exchange among trainees and lecturers.

E.3 Objective of the training course

The objective of the course has been to give the students an introduction to classification methods used in atmospheric sciences, with emphasis on classifications of tropospheric circulation patterns, and their applications in different environmental research fields.

Lectures given by recognized experts from inside and outside the COST733 Action on different topics related to the development, the evaluation and comparison and the application of weather and circulation type classifications should be supported by exercises related to the development, the evaluation and the application of circulation type classifications. The main tool used for these exercises was the COST733CLASS software developed at the University of Augsburg within the frame of the COST733 Action.

E.4 The course of the course

The opening day (Monday, 12 April 10) started with a welcome to all training course participants by J. Jacobeit (Chair of Physical Geography and Vice Dean of the Faculty of Applied Computer Science, University of Augsburg) and R. Huth (Vice Chair of the COST733 Action). After a short introductory round of all trainees the local organizer C. Beck provided organizational details and practical information for the training course.

The first block of lectures provided the trainees with an overview on the background and the objectives of the COST733 action (R. Huth), an introduction to the application of circulation and weather type classifications (R. Huth) and some basic considerations on classifications in climate research (J. Jacobeit).

The development, the properties and the recent status of the COST733 database of circulation type classifications that had been developed within COST733 was presented by A. Philipp. A final lecture (A. Philipp) provided the trainees with basic organizational and technical information related to the practical exercises of the training course. Day one of the training course ended with an informal get-together that gave the opportunity for further discussions among the trainees and lecturers.

Day two of the training course (Tuesday, 13 April 10) was devoted to an introduction to varying methods used for circulation type classification. This day combined lectures on the theoretical background and the basic methodological approaches of selected classifications (A. Philipp) with practical exercises (A. Philipp) using the COST733CLASS software developed at the University of Augsburg within the frame of the COST733 action. These exercises gave the trainees the opportunity to acquire first experience in using the COST733CLASS software.

Evaluation and comparison of circulation type classifications was the main topic of day three (Wednesday, 14 April 10) of the training course. Introductory lectures on evaluation and comparison approaches (C. Beck, R. Huth) were combined with practical exercises (C. Beck) in which the trainees used the COST733CLASS software for performing evaluation and comparison studies of selected classifications.

Day four (Thursday, 15 April 10) started with an introduction to the use of circulation type classifications in different applications (C. Prudhomme, R. Huth). In the following several lectures provided an overview of applications of circulation type classifications in climatology and climate modelling (R. Huth), seasonal forecasting, teleconnection studies and statistical downscaling (R. Benestad) and hydrology (C. Prudhomme) with the latter topic including practical exercises.

Lectures on the last day of the training course (Friday, 16 April 10) were devoted to several applications of circulation type classifications including the analysis of wild fire occurrence (C. Prudhomme on behalf of P. Kassomenos), weather forecasting (T. Krennert), forecasting of snow avalanches (P. Esteban) and finally the use in human health studies (J. Kyselý).

The training school ended with a discussion round on future perspectives of circulation type classifications. In addition to the daily lectures and exercises student poster presentations took place on 3 days of the training course (13, 14, 15 April 10). These poster presentations offered the opportunity for scientific discussions and exchange among trainees and lecturers.

Meetings of the Management Committee (MC) and the Working Groups (WG)

F.1 Management Committee Meetings

The entire group plus external experts had ten meetings during the course of the COST733 Action. These took place in

- MCM1 – 12 September 2005 in Utrecht, The Netherlands;
- MCM2 – 10 March 2006 in Prague, Czech Republic;
- MCM3 – 8 September 2006 in Ljubljana, Slovenia;
- MCM4 – 26 and 27 March 2007 in Florence, Italy;
- MCM5 – 5 and 6 October 2007 in San Lorenzo El Escorial, Spain;
- MCM6 – 9 and 10 May 2008 in Ioannina, Greece
- MCM7 – 22 to 24 October 2008, Krakow, Poland
- MCM8 – 15 to 17 October 2009, Larnaca, Cyprus
- MCM9 – 23 to 24 March 2010, Tartu, Estonia
- MCM10 – 22 to 24 November 2010, Vienna, Austria

F.2 Working Group Meetings

Working Group 1

- 1st Meeting: 13 September 2005, Utrecht, The Netherlands
- 2nd Meeting: 9 March 2006, Prague, Czech Republic
- 3rd and final meeting: 8 and 9 September 2006, Ljubljana, Slovenia

Working Group 2

- 1st Meeting: 9 September 2006, Ljubljana, Slovenia
- 2nd Meeting: 26 and 27 March 2007, Florence, Italy
- 3rd Meeting: 5 and 6 October 2007, San Lorenzo El Escorial, Spain
- 4th Meeting: 8 and 9 March 2008, Augsburg, Germany
- 5th Meeting: 9 and 10 May 2008, Ioannina, Greece
- 6th Meeting: 26 to 28 March 2008, Toulouse, France
- 7th Meeting: 15 to 17 October 2009, Larnaca, Cyprus
- 8th Meeting: 23 to 24 March 2010, Tartu, Estonia
- 9th Meeting: 22 to 24 November 2010, Vienna, Austria

Working Group 3

- 1st Meeting: 9 September 2006, Ljubljana, Slovenia
- 2nd Meeting: 26 and 27 March 2007, Florence, Italy
- 3rd Meeting: 5 and 6 October 2007, San Lorenzo El Escorial, Spain
- 4th Meeting: 22 and 23 February 2008, Barcelona, Spain
- 5th Meeting: 9 and 10 May 2008, Ioannina, Greece
- 6th Meeting: 9 and 10 March 2009, Brussels, Belgium (10 March joint with Working Group 4)
- 7th Meeting: 23 to 24 March 2010, Tartu, Estonia
- 8th Meeting: 22 to 24 November 2010, Vienna, Austria

Working Group 4

- 1st Meeting: 9 September 2006, Ljubljana, Slovenia
- 2nd Meeting: 26 and 27 March 2007, Florence Italy
- 3rd Meeting: 5 and 6 October 2007, San Lorenzo El Escorial, Spain
- 4th Meeting: 7 and 8 March 2008, Brussels, Belgium
- 5th Meeting: 9 and 10 May 2008, Ioannina, Greece
- 6th Meeting: 10 and 11 March 2009, Brussels, Belgium (10 March joint with Working Group 3)
- 7th Meeting: 15 to 17 October 2009, Larnaca, Cyprus
- 8th Meeting: 23 to 24 March 2010, Tartu, Estonia
- 9th Meeting: 22 to 24 November 2010, Vienna, Austria